

# 3D Scanning

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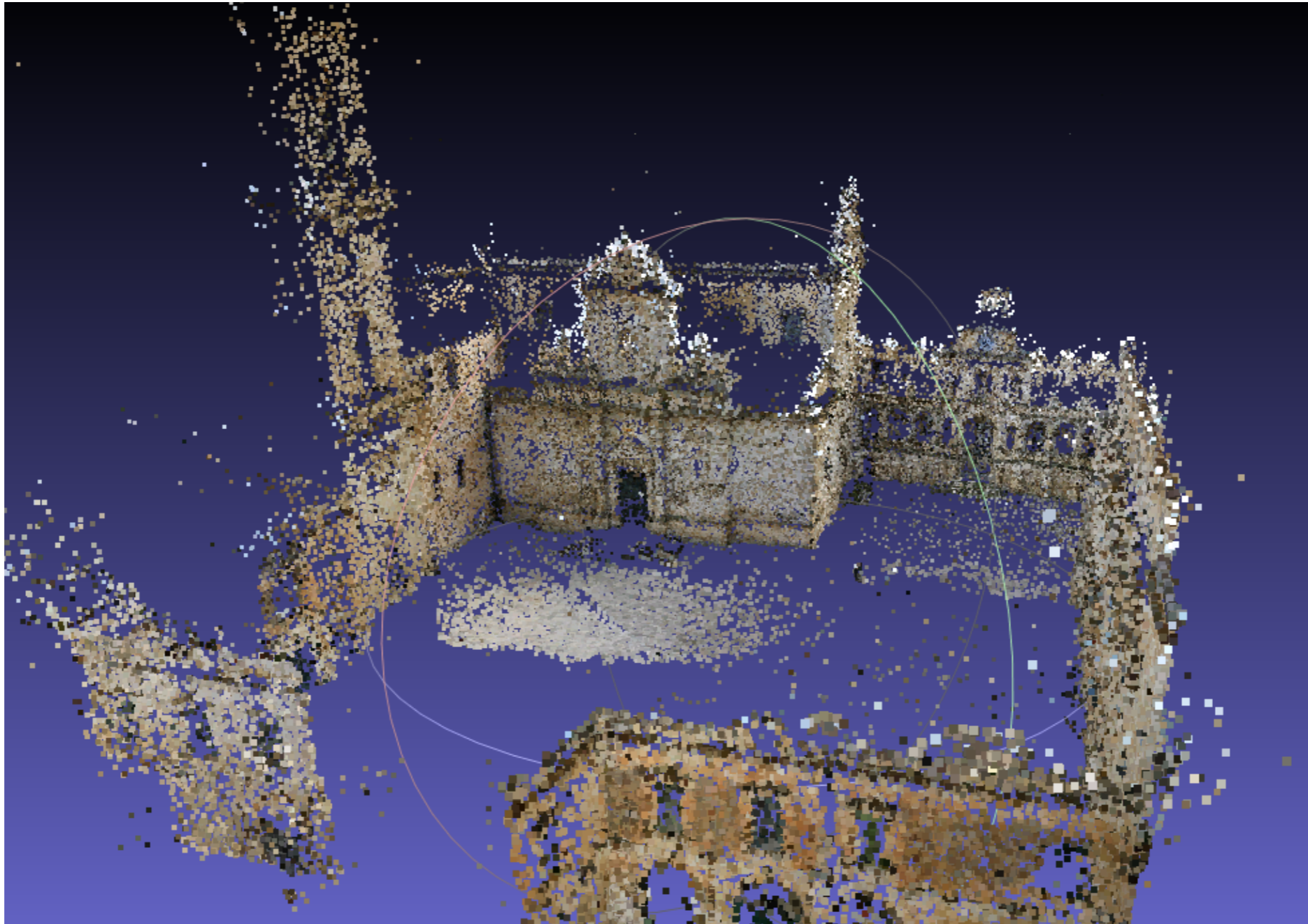
# What is 3D Scanning?

- 3D scanning is the process of ***measuring*** 3D information.
- This is the very first step when creating a complete 3D model.

# 3D Scanning Outputs

- Each device outputs measure 3D information differently. The main outputs are:
  - 3D sparse points
  - Range maps
  - 3D volumes

# 3D Scanning Outputs: Sparse Points

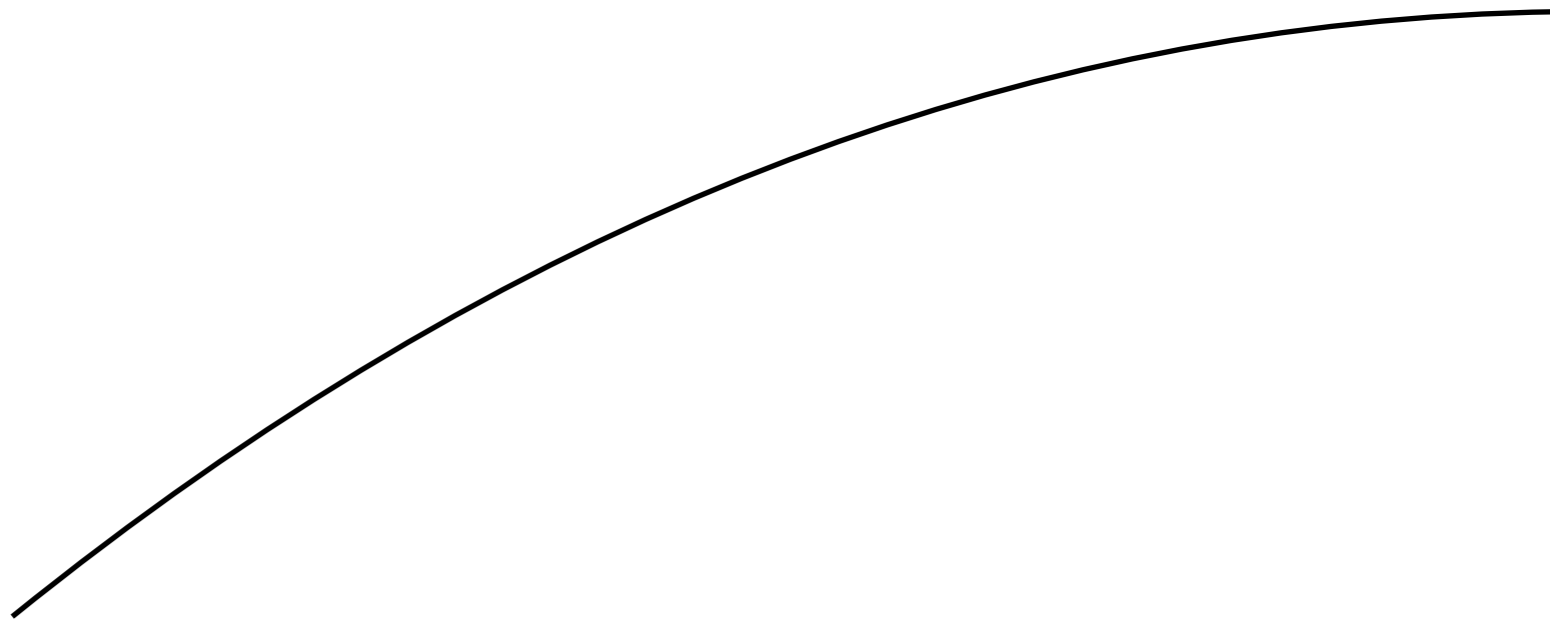


# 3D Scanning Outputs: Sparse Points

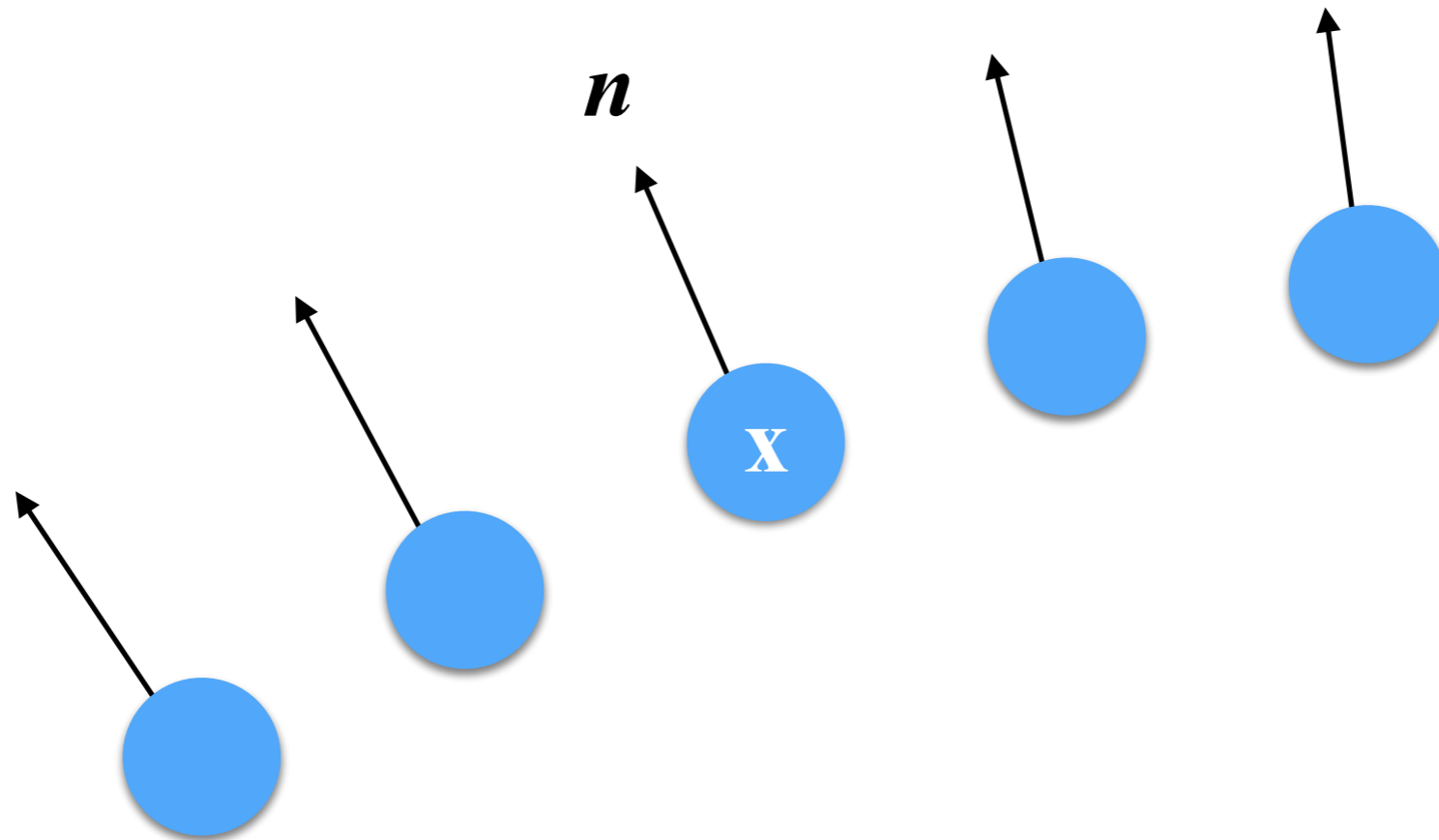
- Each point can have attributes:
  - An RGB color and/or optical properties
  - Surface's normal
  - ...
- Metadata: position and orientation of the origin, and its scale

# 3D Scanning Outputs: Sparse Points

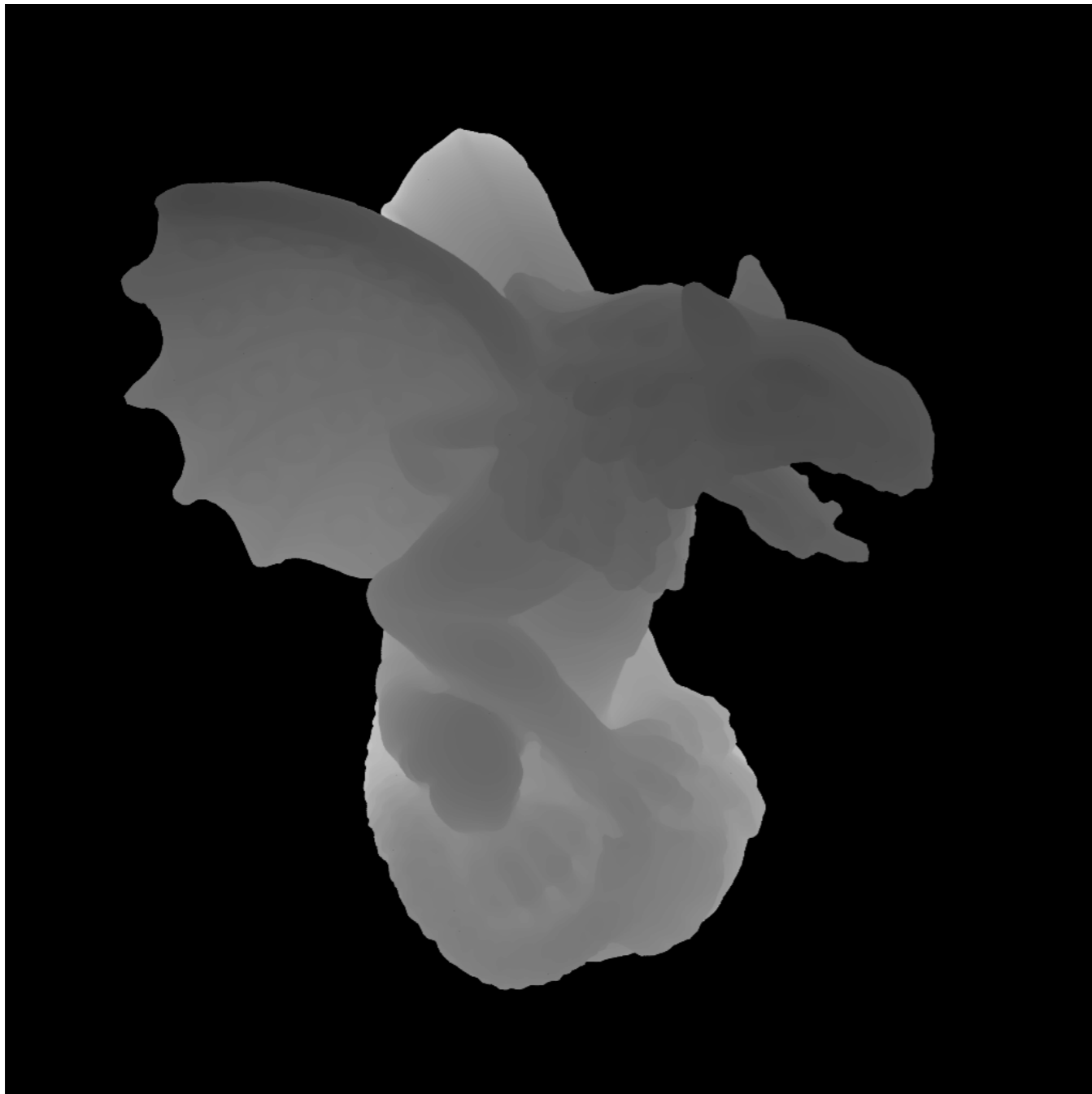
3D surface



# 3D Scanning Outputs: Sparse Points



# 3D Scanning Outputs: Range Maps



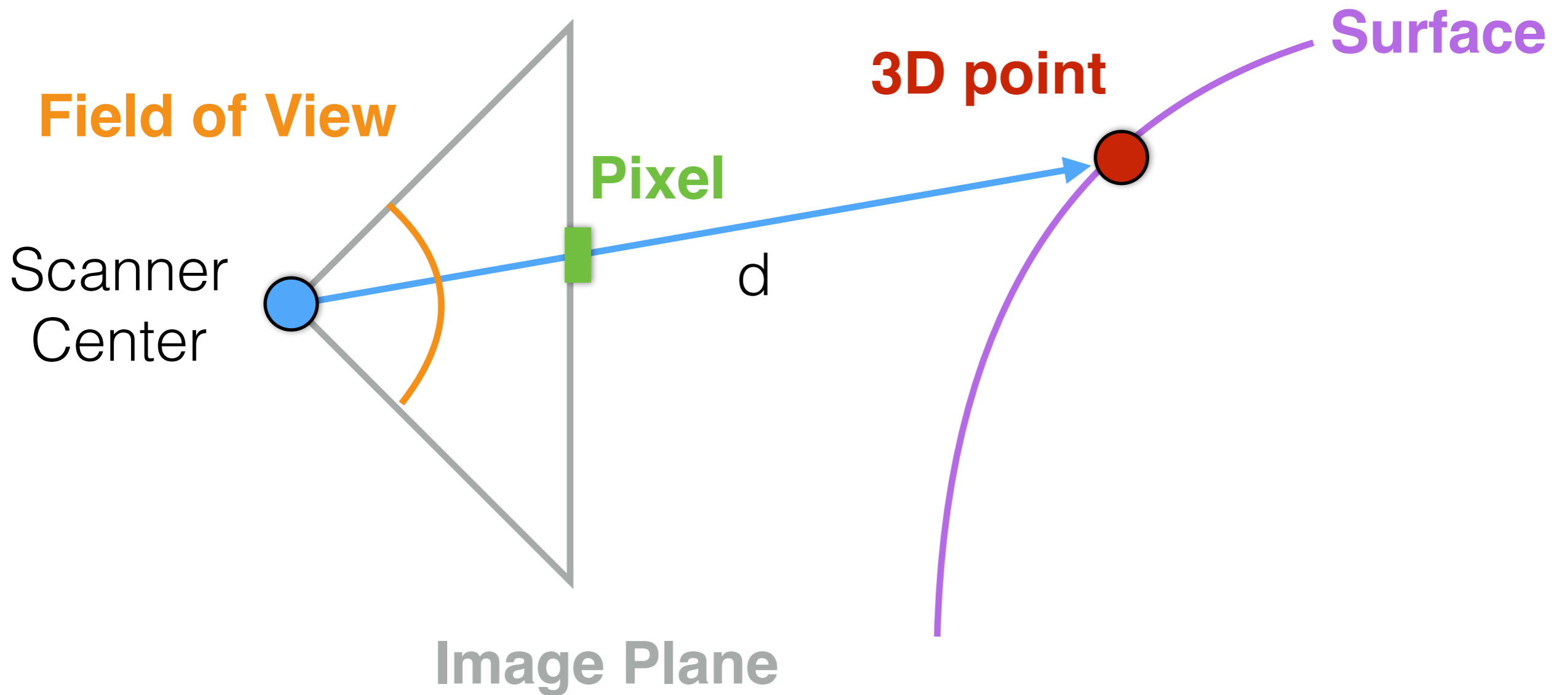
Each pixel in the image encodes the distance between the surface and center of the camera



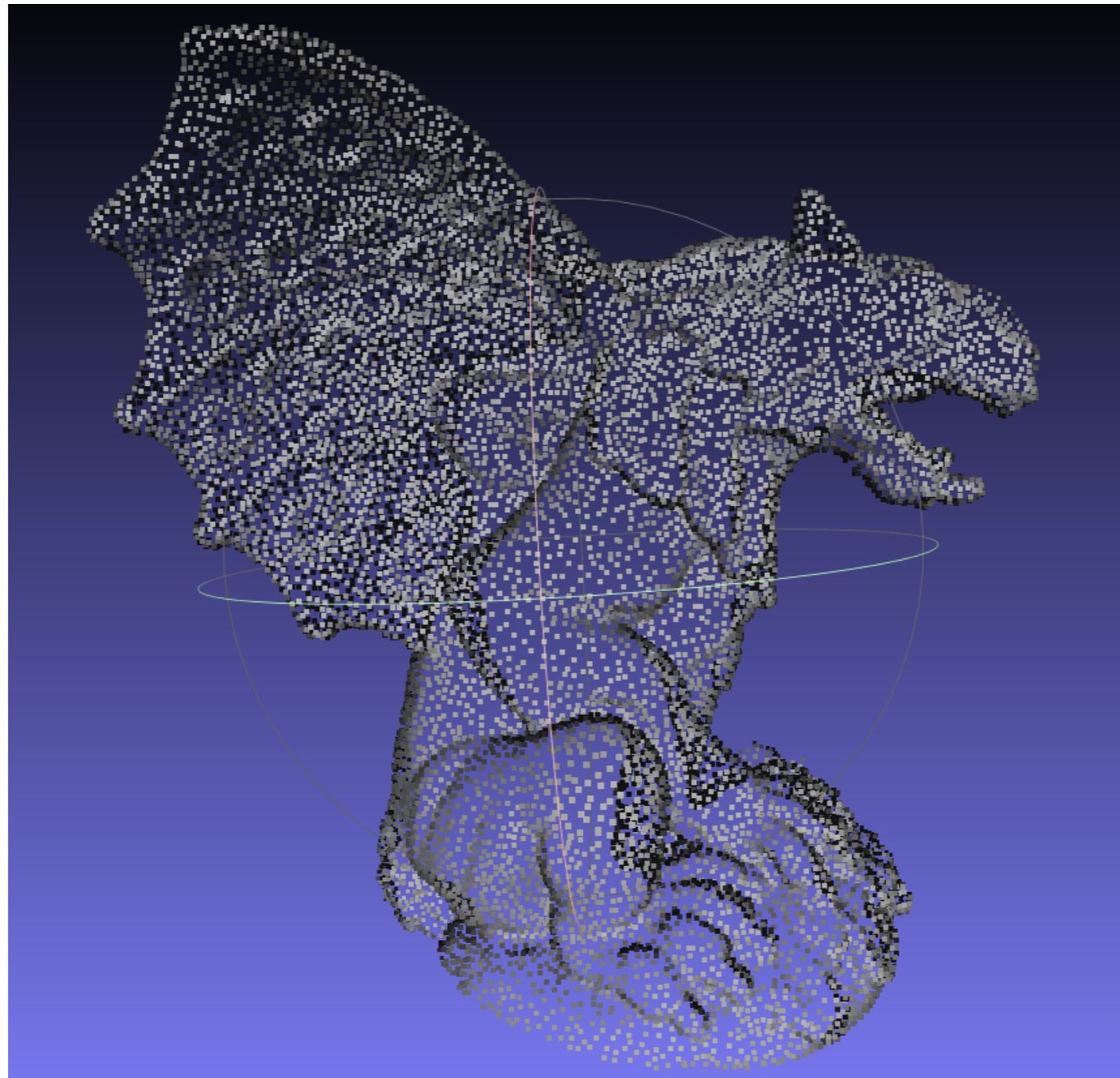
# 3D Scanning Outputs: Range Maps

- Metadata:
  - Camera extrinsics: position and rotation
  - Camera intrinsics: field of view, size of pixels in mm
  - Scale of distances
- From Metadata:
  - we can obtain 3D points!

# 3D Scanning Outputs: Range Maps



# 3D Scanning Outputs: Range Maps



# 3D Scanning Outputs: Range Maps

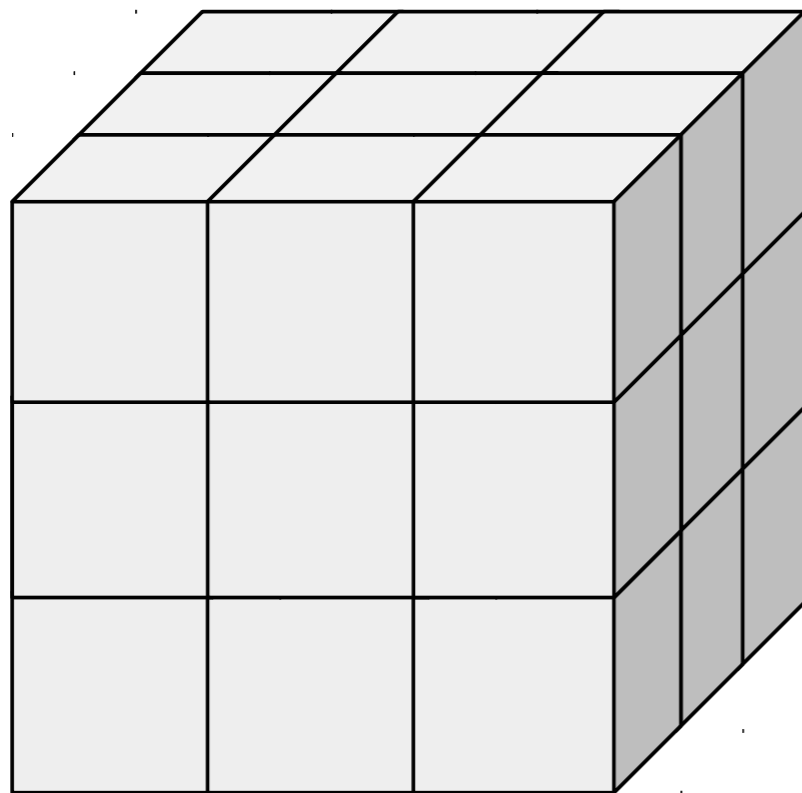
- A range map is already a 3D model... but it will be surely incomplete
- A single acquisition ***IS NOT enough*** to reconstruct an entire object
- Multiple shots are needed...
  - How many?
  - Which ones to choose?

# 3D Scanning Outputs: Range Maps

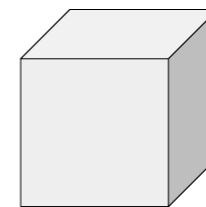


# 3D Scanning Outputs: 3D Volumes

- 3D space is discretized into a regular grid or ***volume***
- Each cube in the grid is called ***voxel*** (volume pixel) or a cube encodes a value in the range  $[0, 1]$ .



Volume



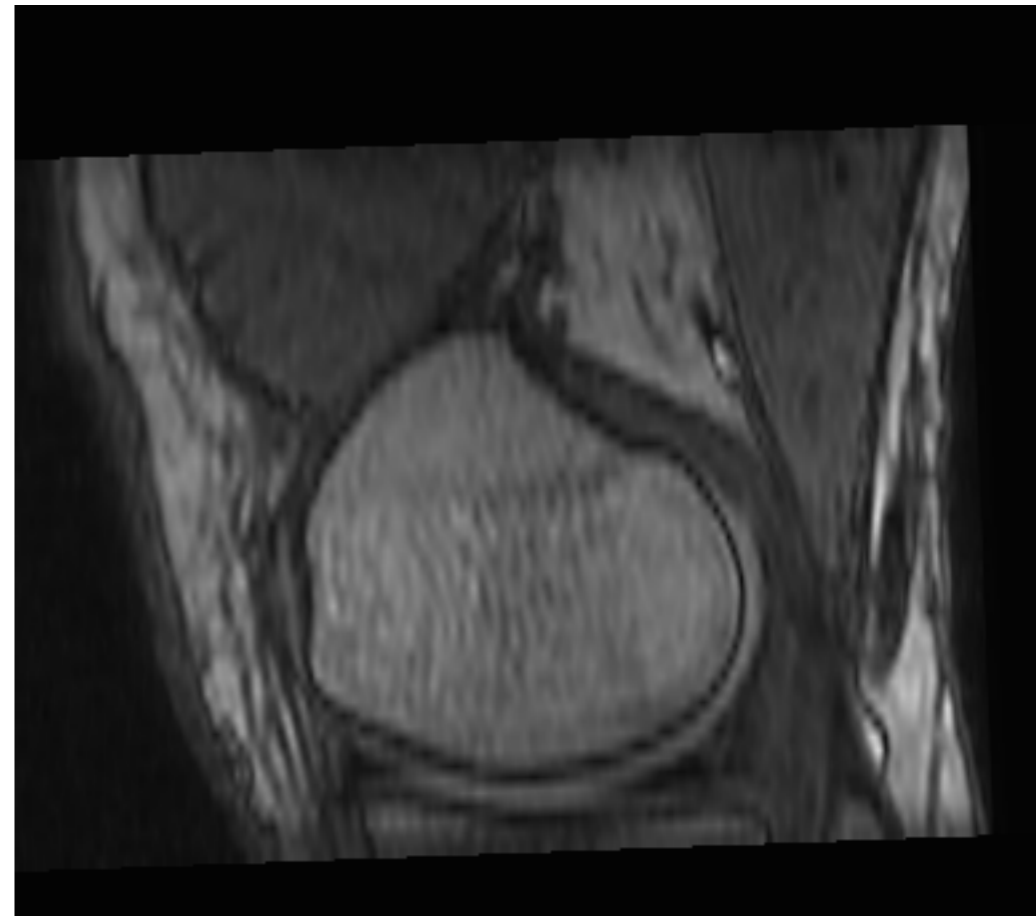
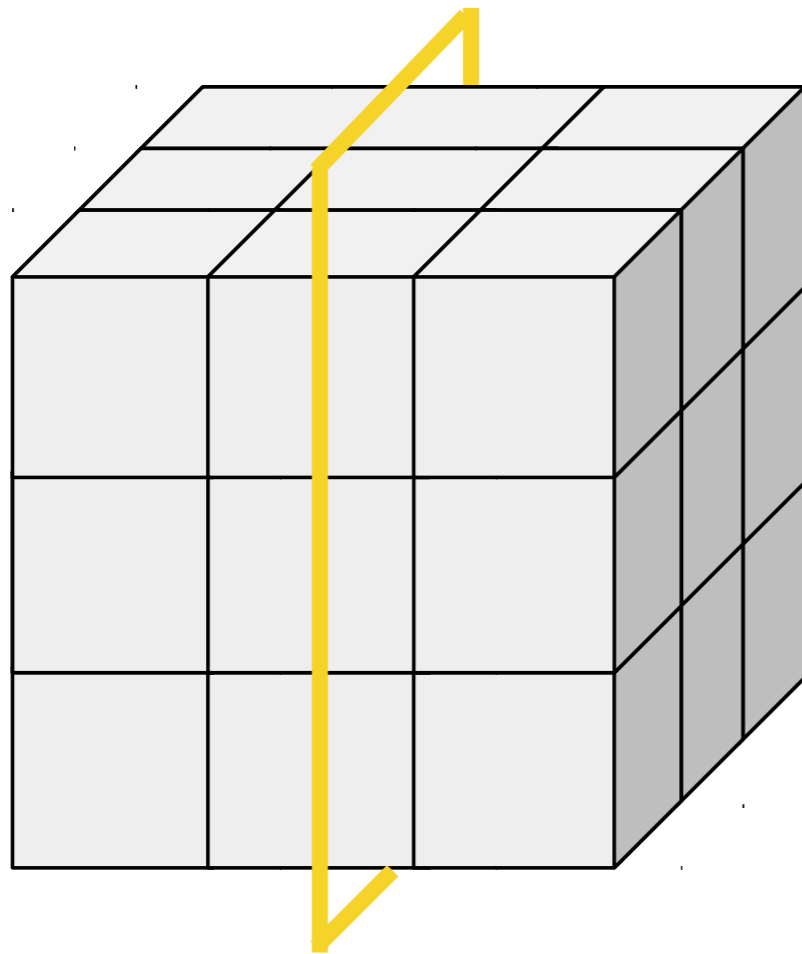
Voxel

# 3D Scanning Outputs: 3D Volumes

- Metadata:
  - size of the pixel in mm for each slice
  - distance in mm between a slice and another
  - scale of the normalized values (typically encoded as 16-bit values)

# 3D Scanning Outputs: 3D Volumes

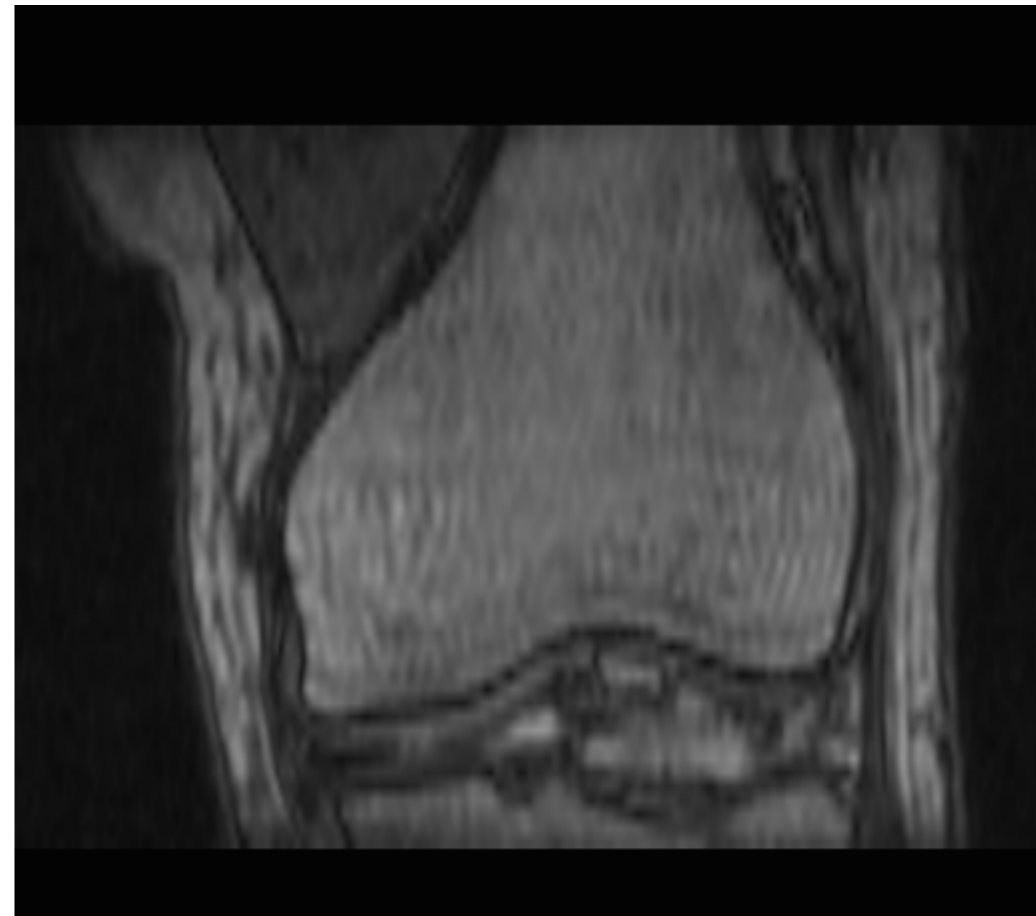
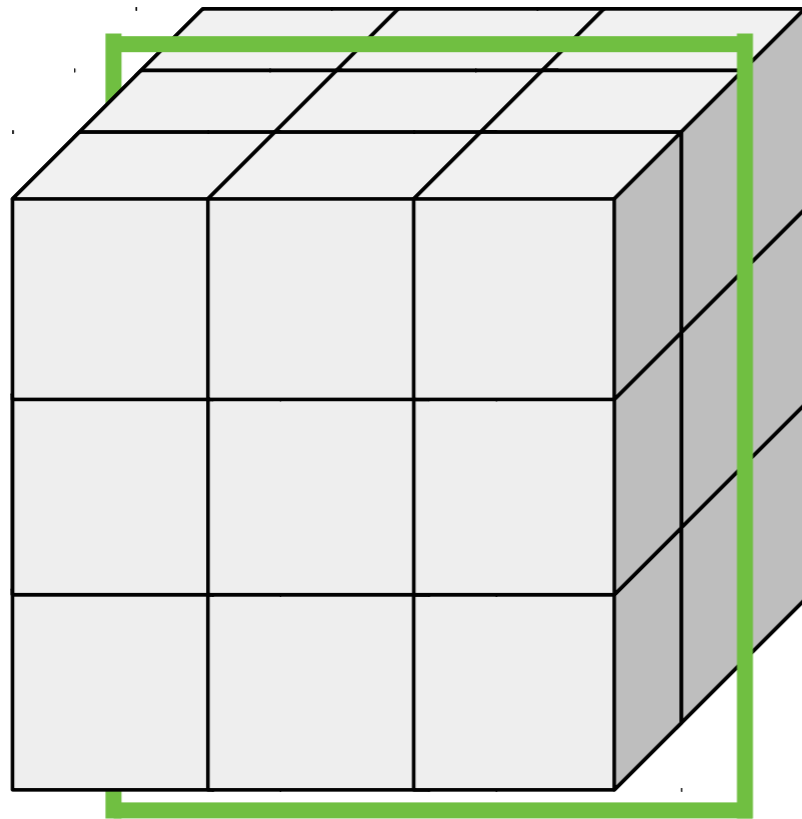
- A ***sagittal plane*** is an anatomical plane that divides the body into right and left parts





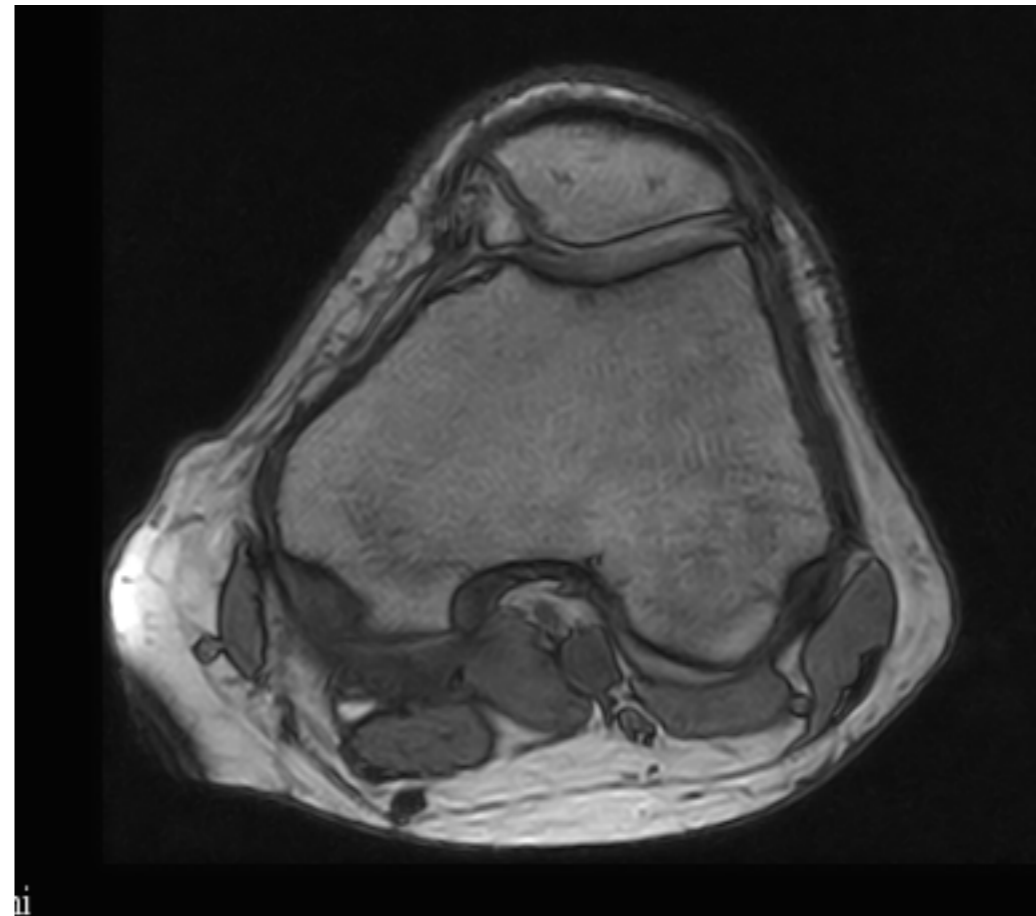
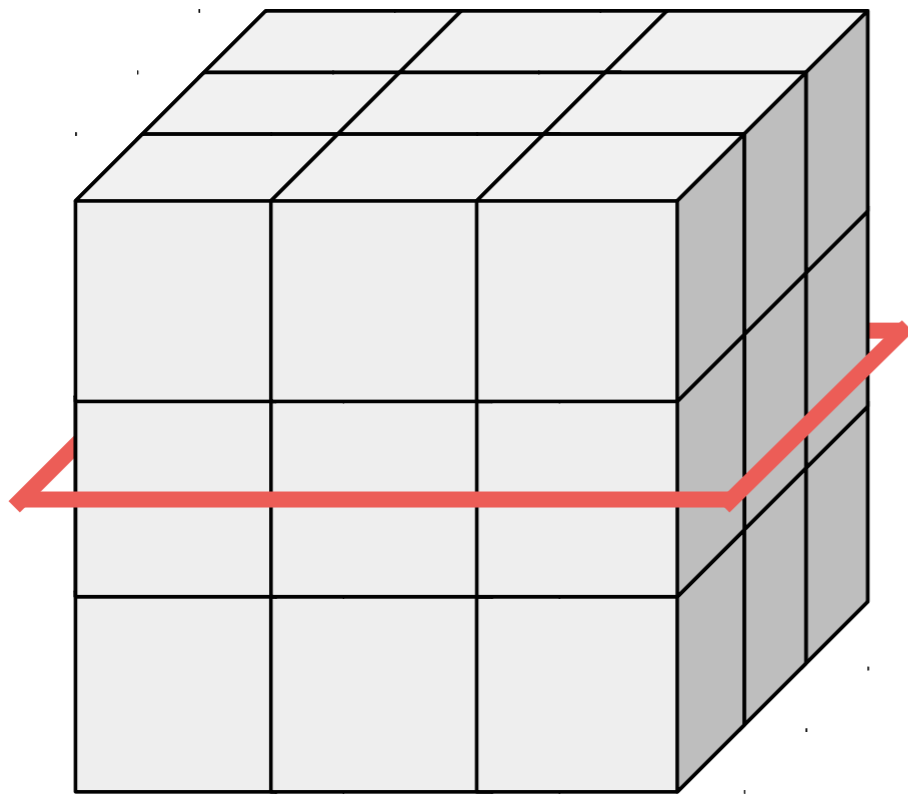
# 3D Scanning Outputs: 3D Volumes

- A ***coronal plane*** is an anatomical plane that divides the body into ventral and dorsal parts



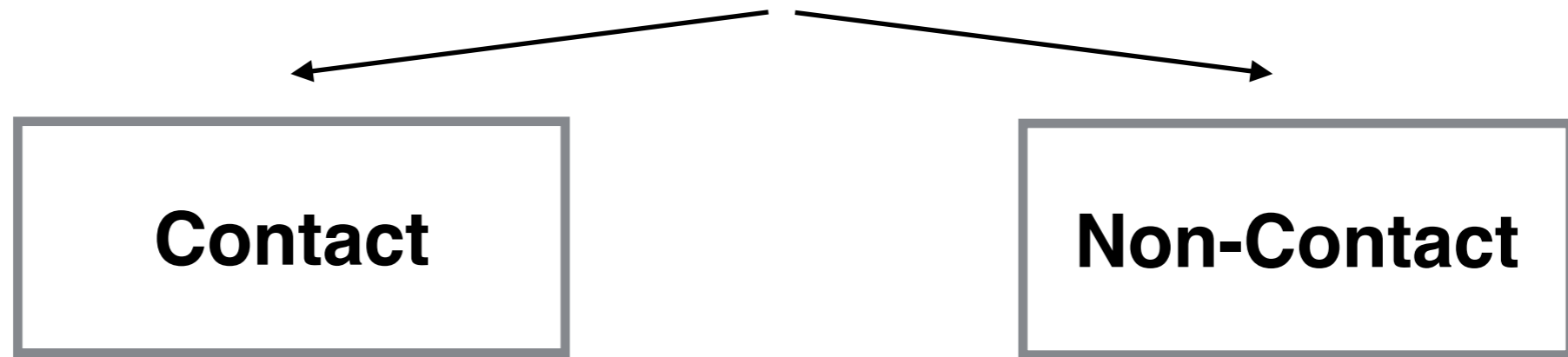
# 3D Scanning Outputs: 3D Volumes

- An ***axial plane*** is an anatomical plane that divides the body into superior and inferior parts

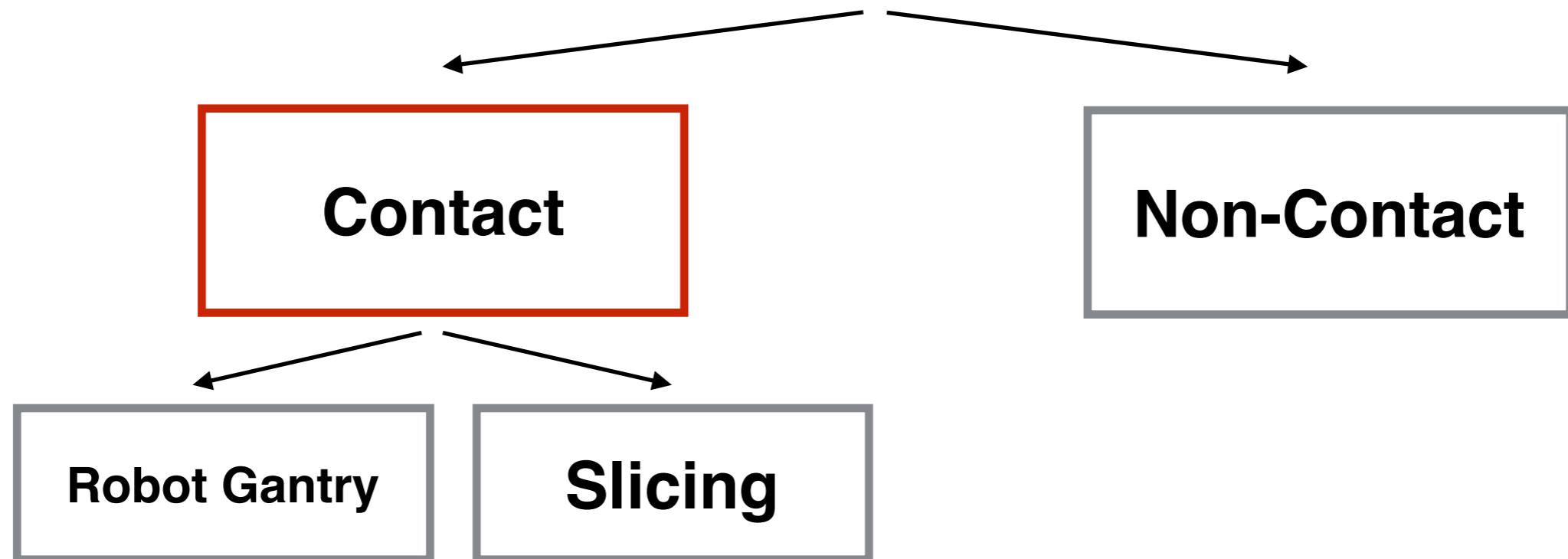


# 3D Scanning Taxonomy

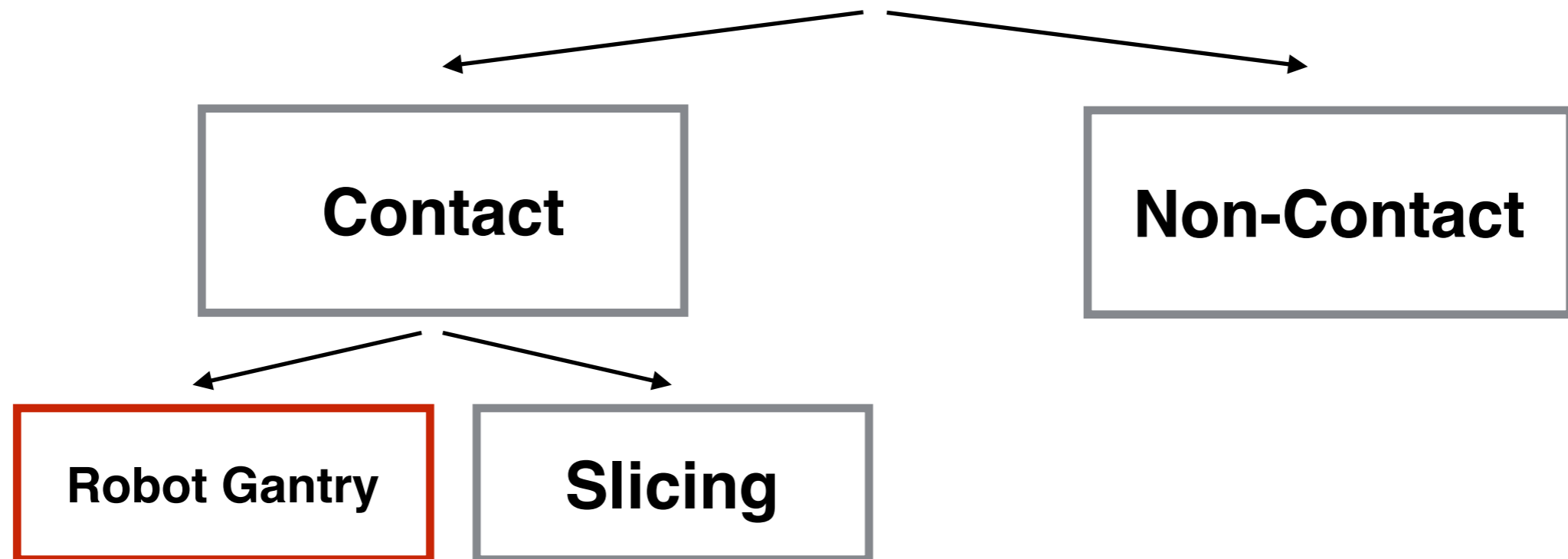
# 3D Scanning Taxonomy



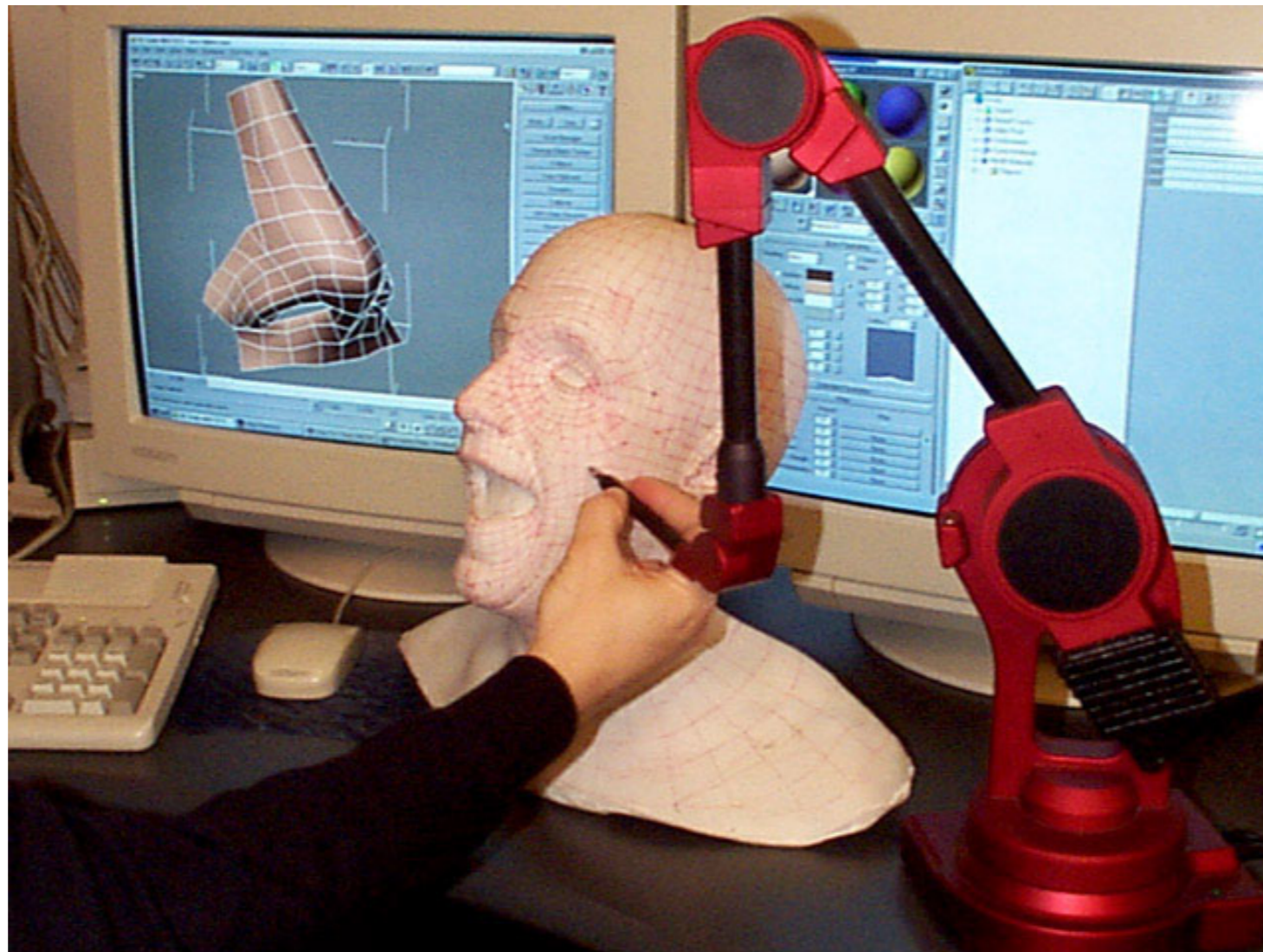
# 3D Scanning Taxonomy



# 3D Scanning Taxonomy



# 3D Scanning Taxonomy: Robot Gantry



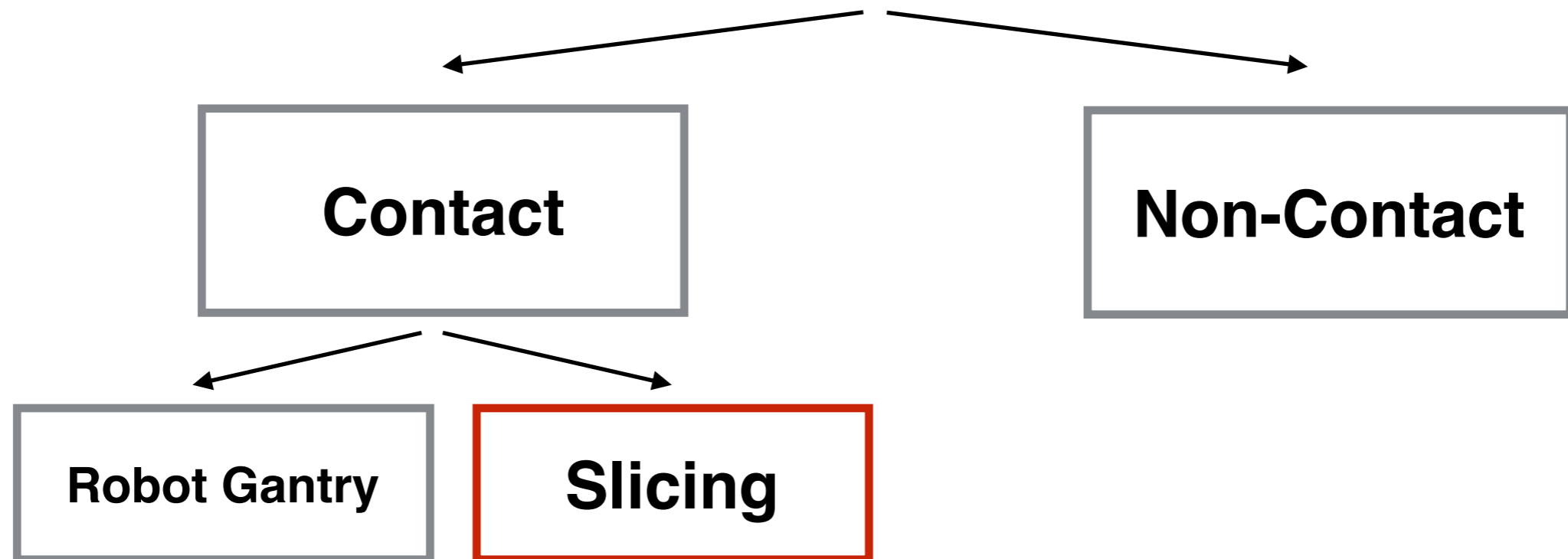
Object is “*probed*” at different locations

# 3D Scanning Taxonomy: Robot Gantry

- Highly accurate (micron)
- Moderate-high costs: \$2,000 - \$15,000
- Slow scanning; labor intensive!
- Ideal for: rigid and non-fragile objects
- Uses: manufacturing control, art/design, reverse engineering
- Output data: sparse 3D points



# 3D Scanning Taxonomy



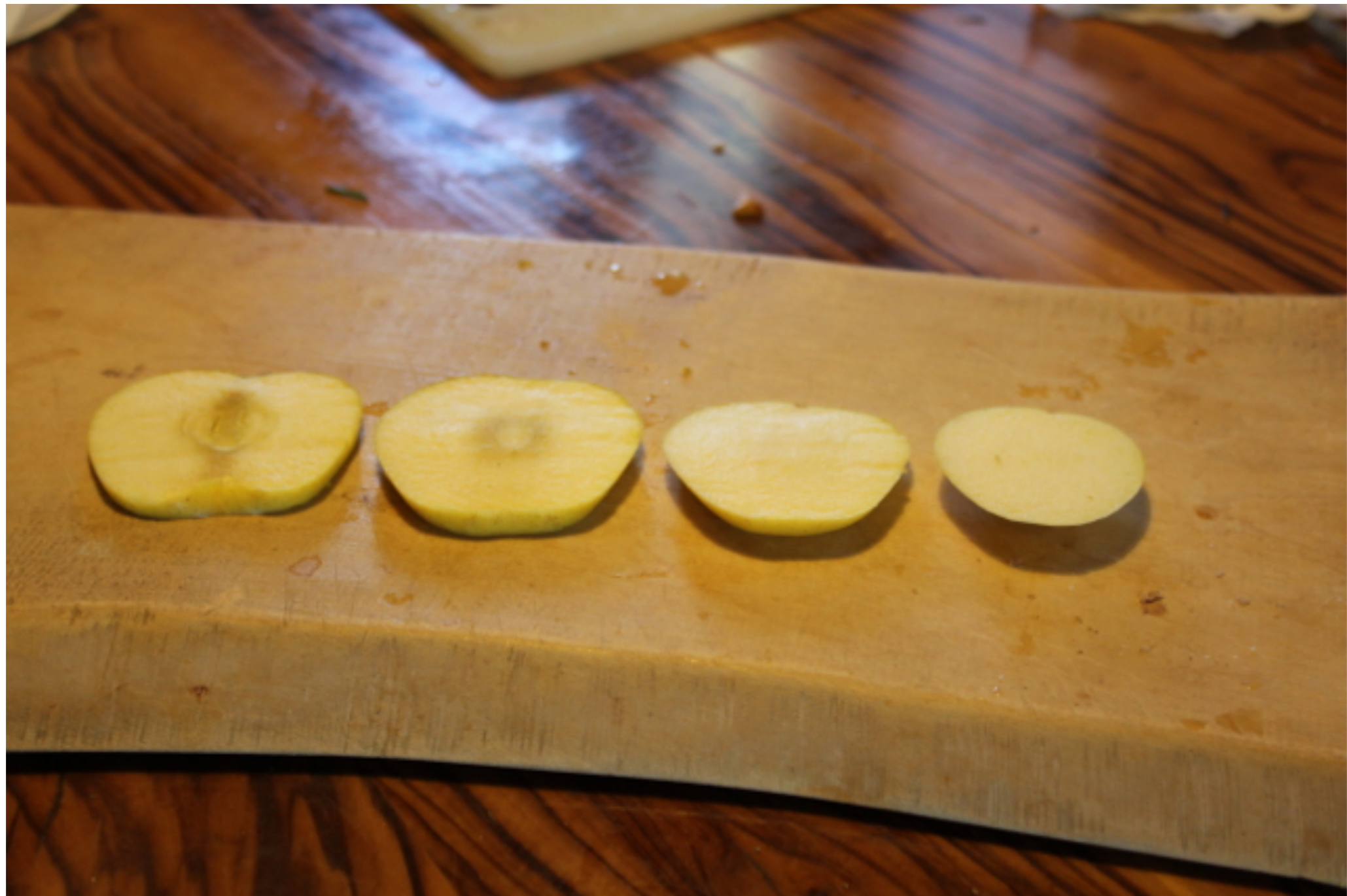
# 3D Scanning Taxonomy: Slicing



# 3D Scanning Taxonomy: Slicing



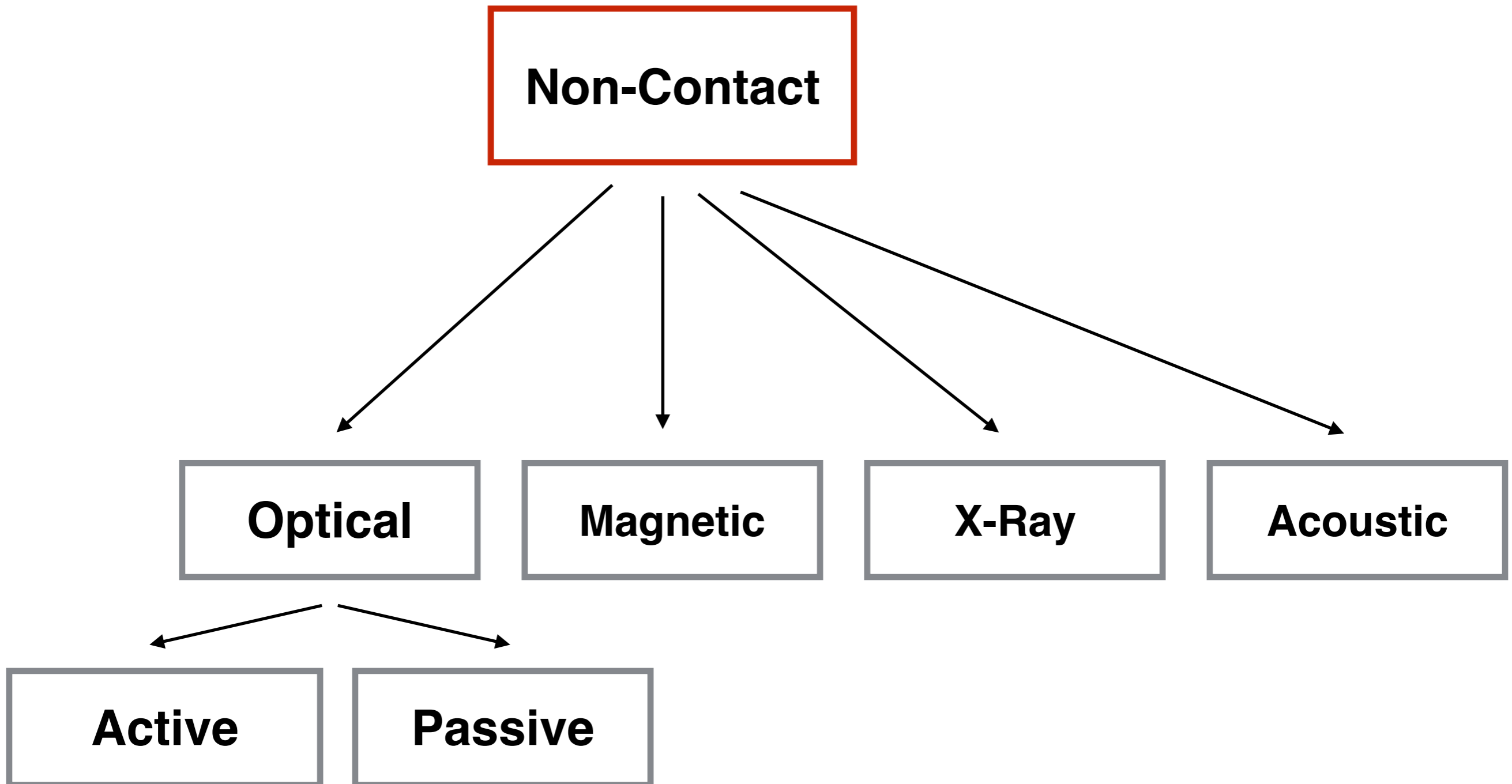
# 3D Scanning Taxonomy: Slicing



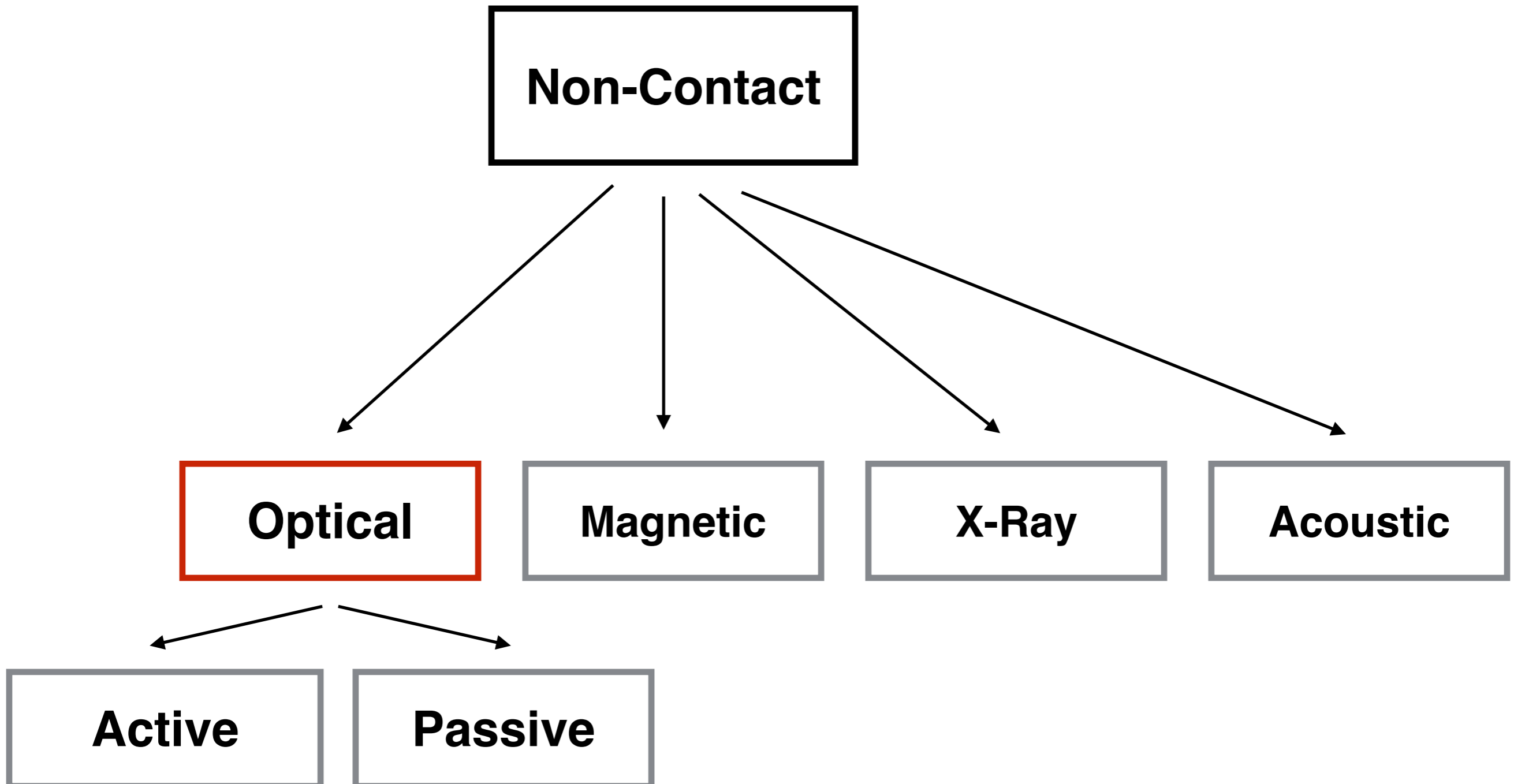
# 3D Scanning Taxonomy: Slicing

- It can be accurate and precise; if slicing is automatic
- Slow scanning
- Ideal for:
  - rigid and non-deformable objects
  - breakable objects
- Uses: biology, reverse engineering
- Output data: a 3D volume (in this case we can have a per voxel color)

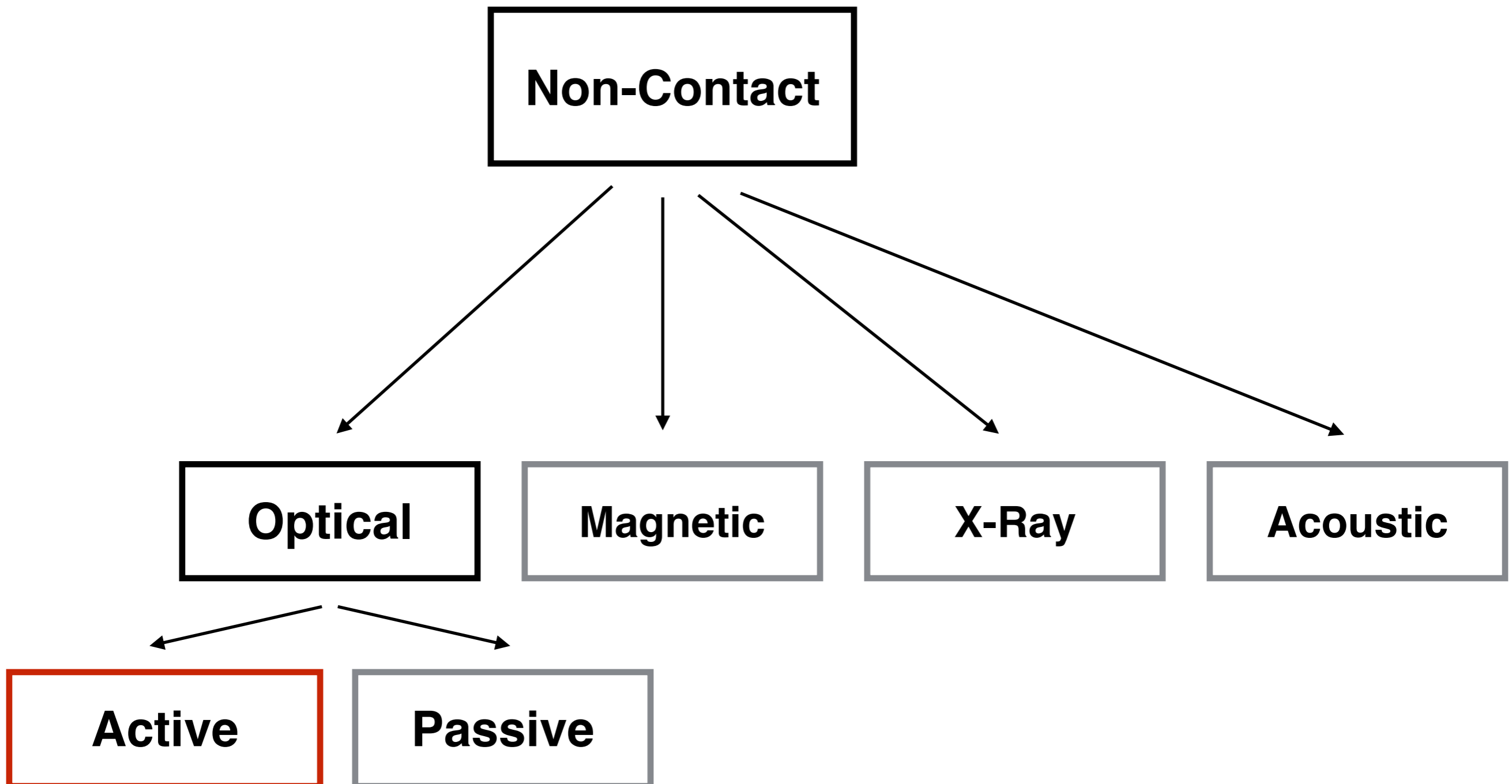
# 3D Scanning Taxonomy



# 3D Scanning Taxonomy



# 3D Scanning Taxonomy

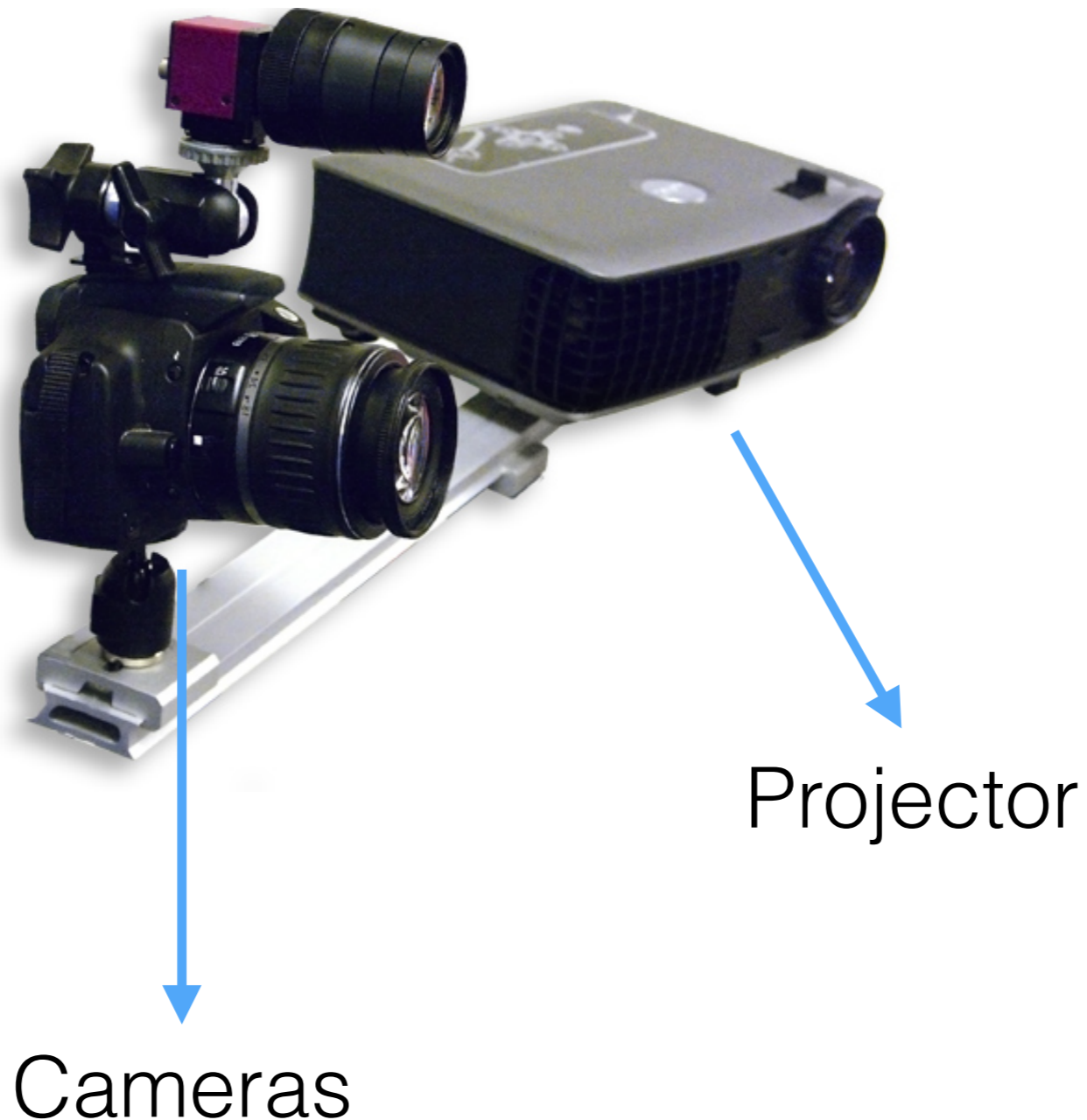




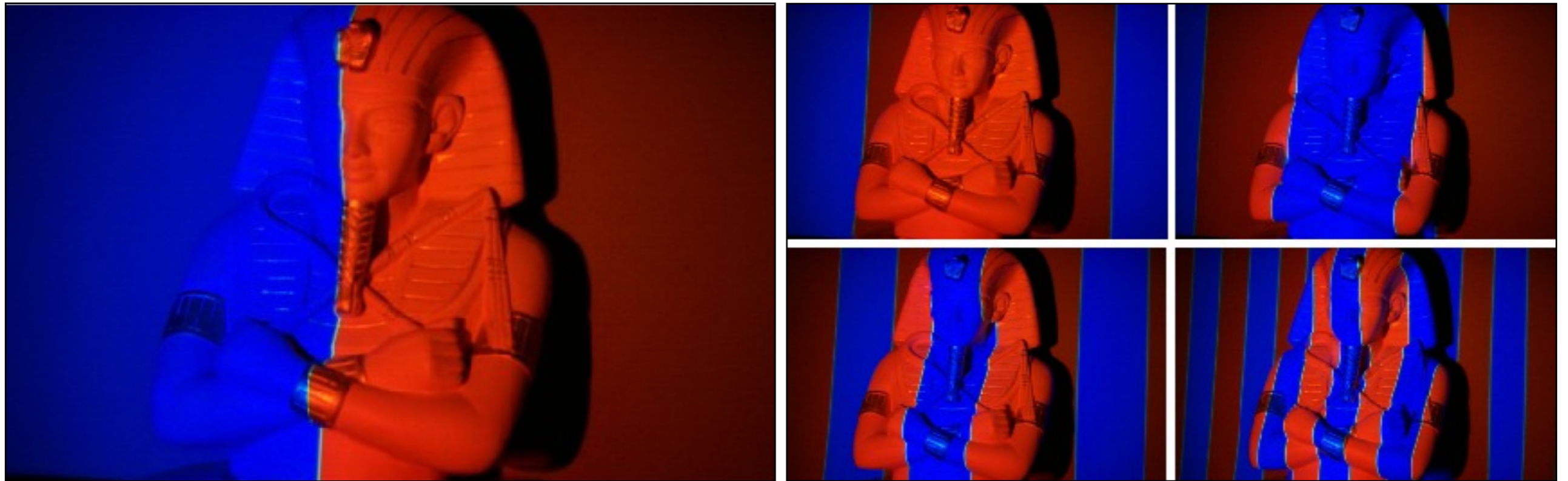
# 3D Scanning Taxonomy: Optical - Active

- Main blocks:
  - A calibrated camera
  - A light source —> that's why it's *active*!

# 3D Scanning Taxonomy: Optical - Active: Structured Light



# 3D Scanning Taxonomy: Optical - Active: Structured Light



# 3D Scanning Taxonomy: Optical - Active: Structured Light



Breuckmann GmbH

Cost: €70,000-80,000

Accuracy: 0.1 mm

# 3D Scanning Taxonomy: Optical - Active: Structured Light



Microsoft Kinect v1

Cost: €100

Accuracy: 2-5 mm

# 3D Scanning Taxonomy: Optical - Active: Laser-based

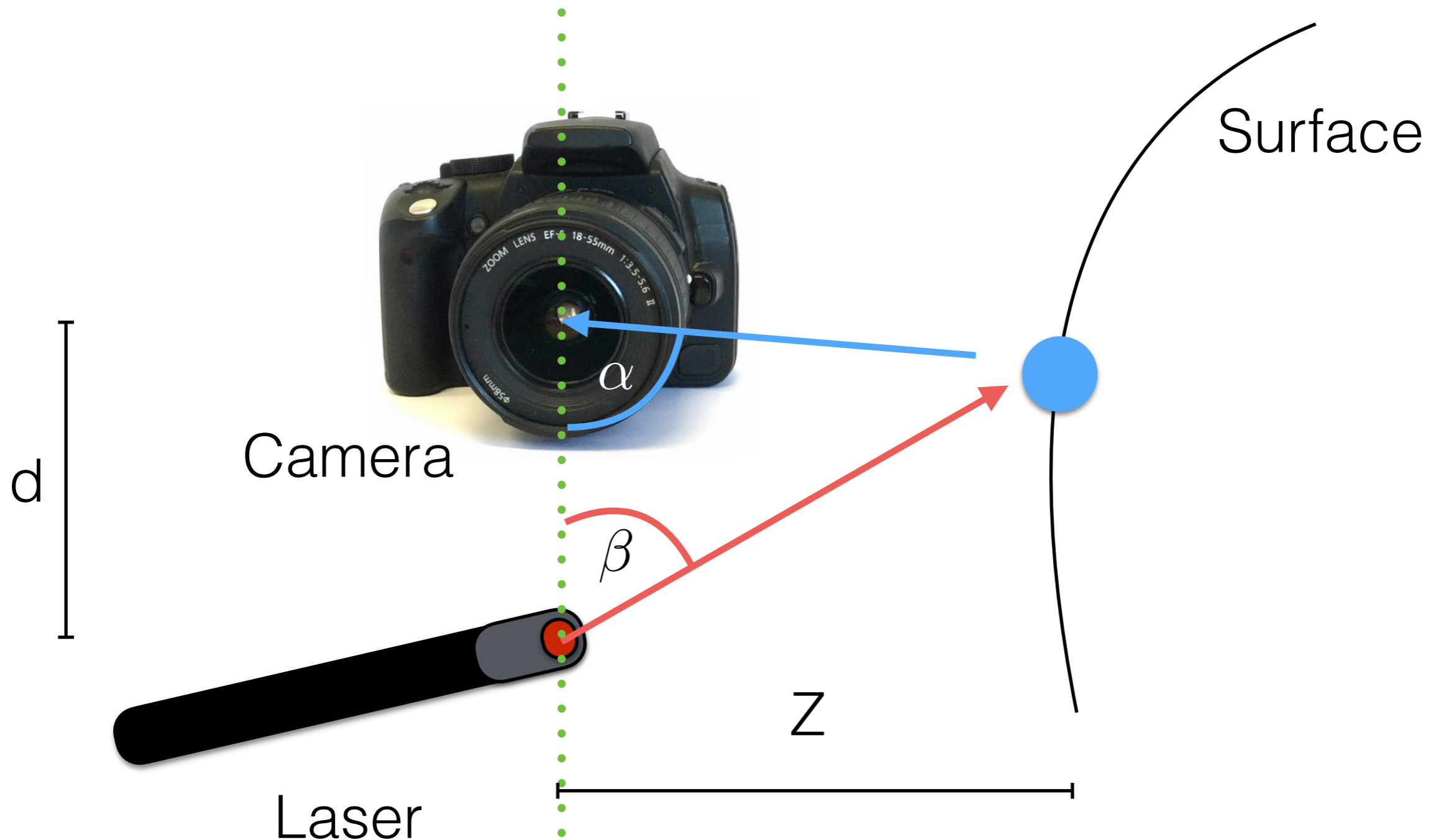


Laser Line



Camera

# 3D Scanning Taxonomy: Optical - Active: Laser-based



# 3D Scanning Taxonomy: Optical - Active: Laser-based



Konica Minolta Range 7

Cost: \$80,000

Accuracy: 40 micron



# 3D Scanning Taxonomy: Optical - Active: Laser-based



Konica Minolta Vivid 910

Cost: \$15,000 (second hand)

Accuracy: 0.2-0.3mm

# 3D Scanning Taxonomy: Optical - Active: Laser-based

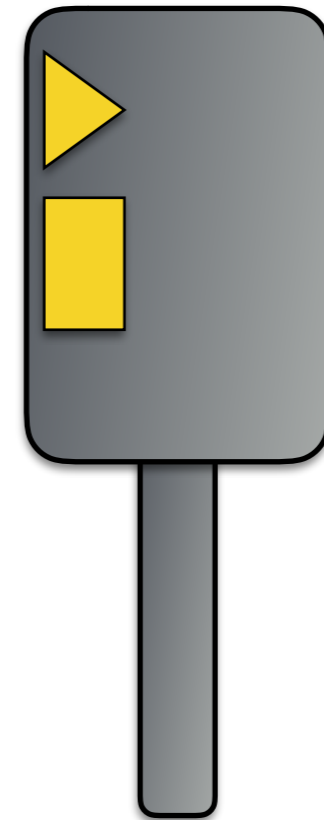


NextEngine

Cost: \$2,000

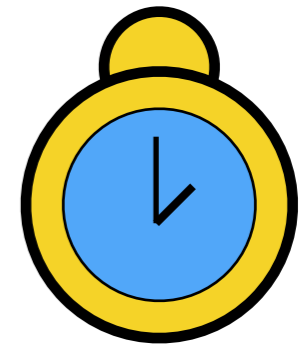
Accuracy: 0.2-0.5mm

# 3D Scanning Taxonomy: Optical - Active: Time-of-flight



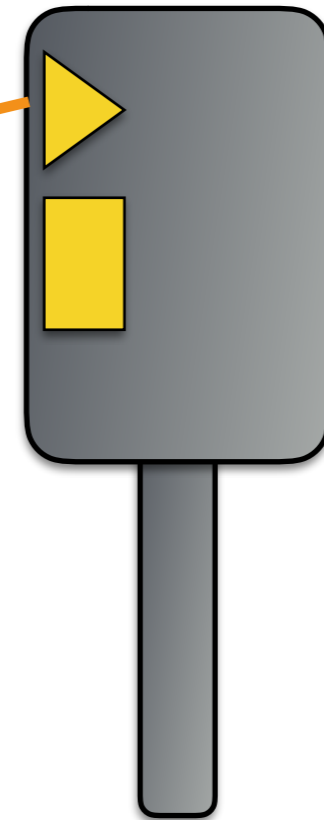
Transmitter

Detector



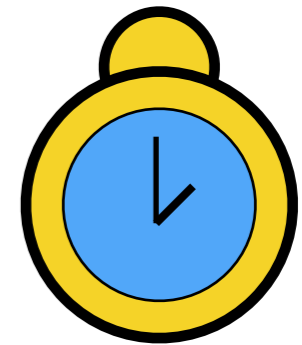
Clock

# 3D Scanning Taxonomy: Optical - Active: Time-of-flight



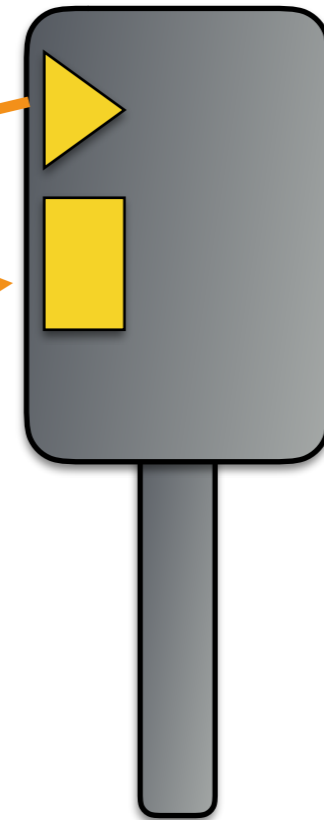
Transmitter

Detector



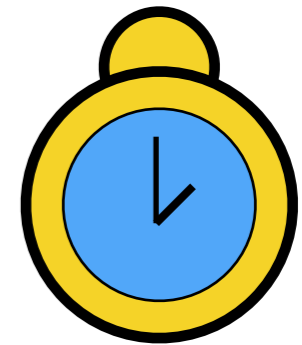
Clock

# 3D Scanning Taxonomy: Optical - Active: Time-of-flight



Transmitter

Detector



Clock

# 3D Scanning Taxonomy: Optical - Active: Time-of-flight



Microsoft Kinect v2

Cost: €200

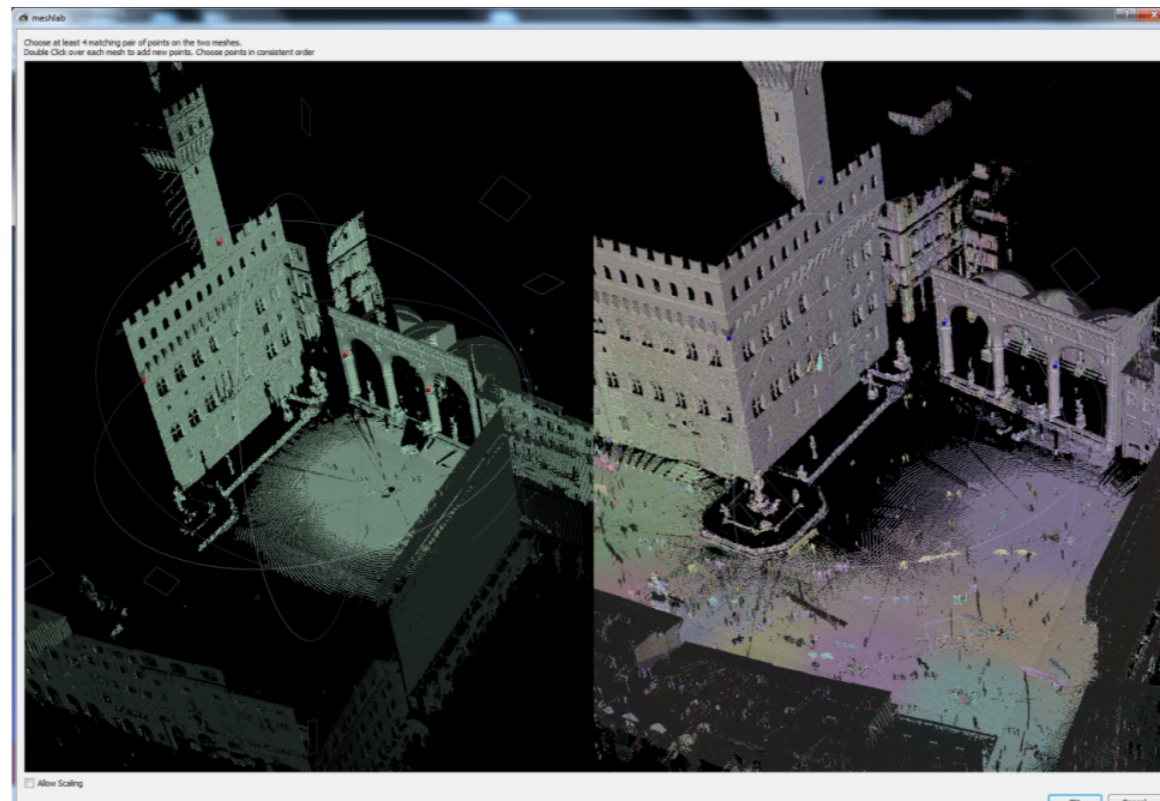
Accuracy: 2-5 mm

It is meant for ***small*** environments: 2-3m radius

# 3D Scanning Taxonomy: Optical - Active: Time-of-flight



Cost: €50,000 - 100,000  
Accuracy: 5-10 mm



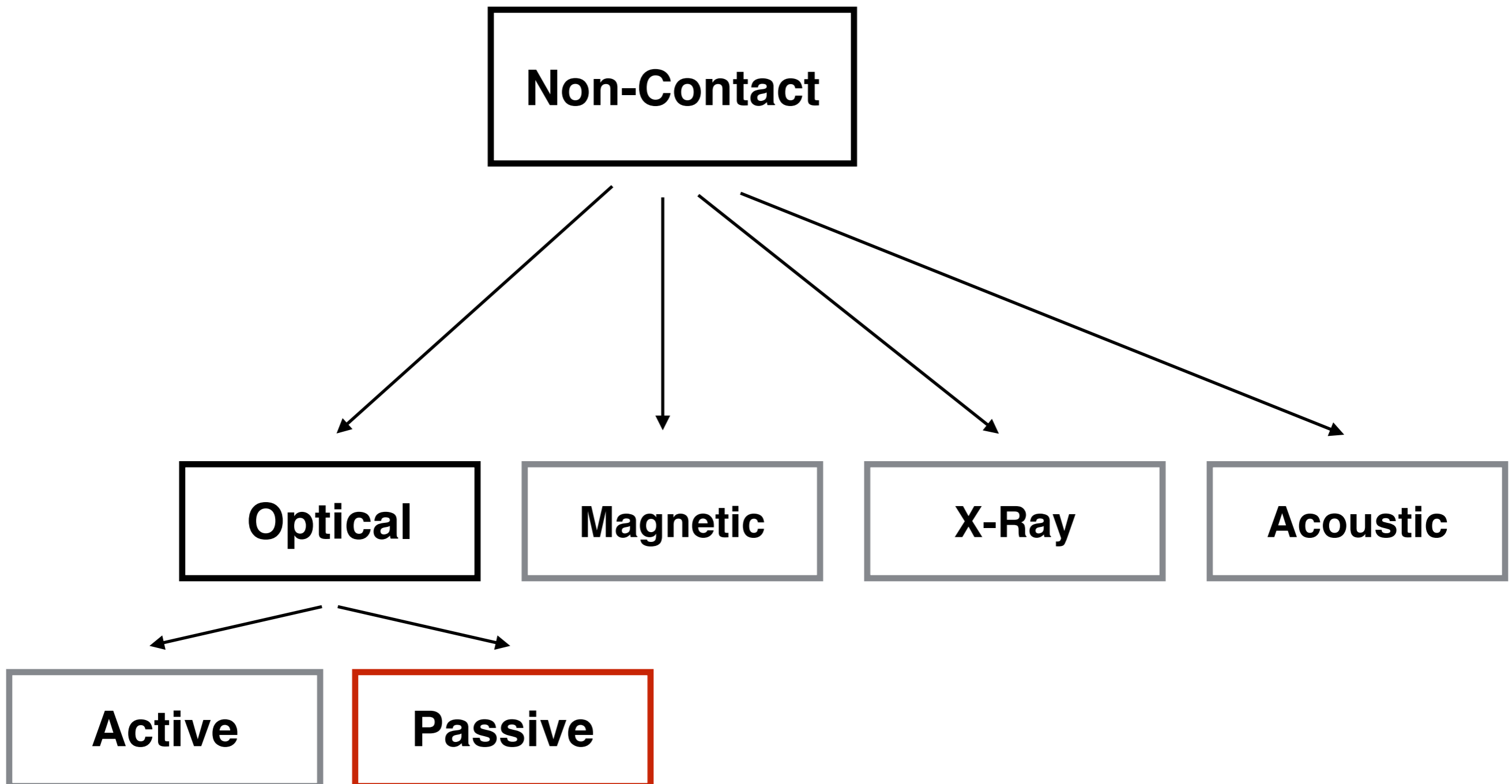
It is meant for  
**large**  
environments:  
1-30m radius

# 3D Scanning Taxonomy: Optical - Active

- It can be accurate and precise
- Ideal for: rigid object with diffuse optical properties; i.e., it does not work well for specular surfaces and dark materials
- Uses: reverse engineering, cultural heritage, metrology (if calibrated), body scanning, etc.
- Costs: from \$200 to \$100,000
- Output data: a range map



# 3D Scanning Taxonomy



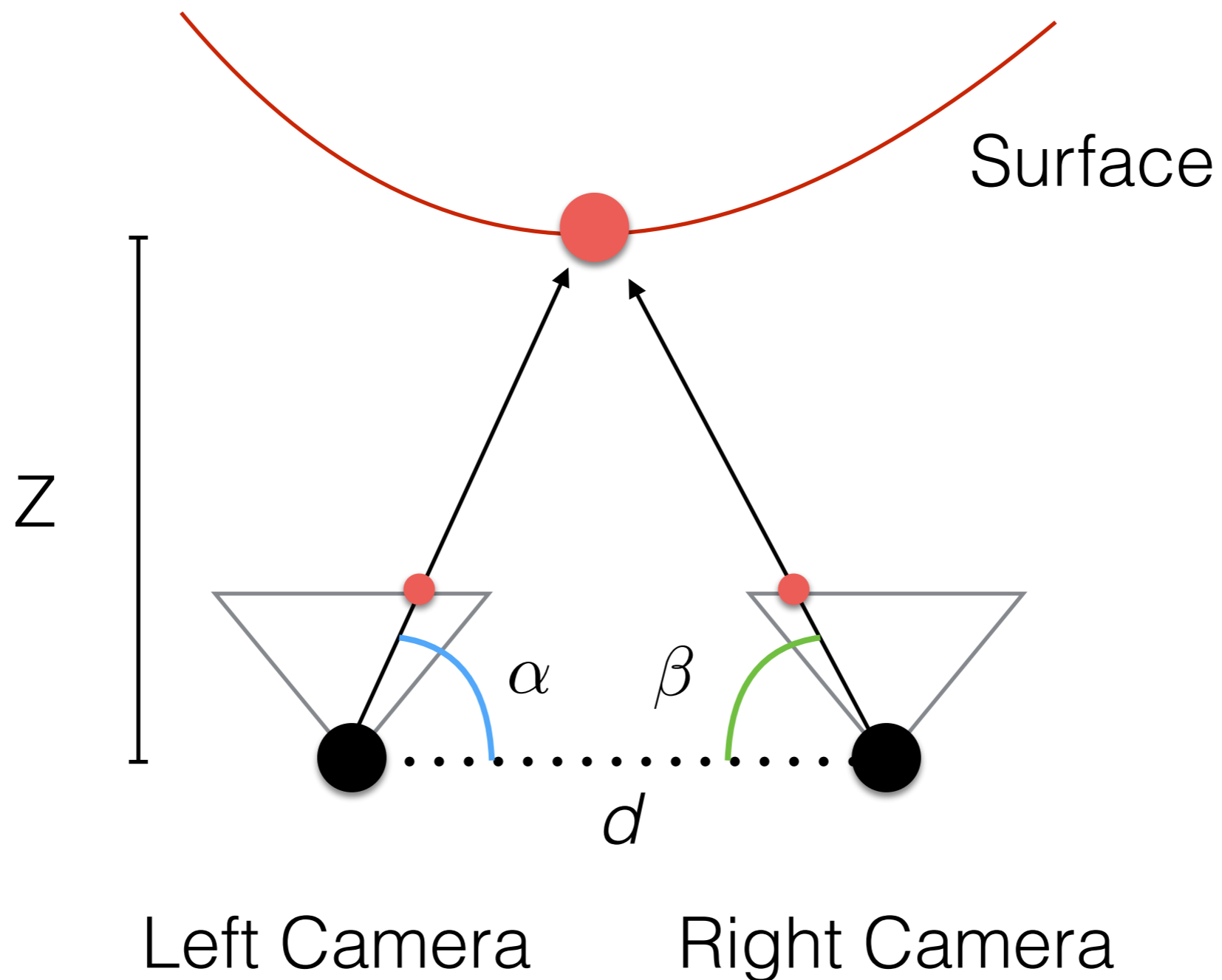
# 3D Scanning Taxonomy: Optical - Passive

- Main blocks:
  - One or more calibrated camera(s)
  - No control on lighting —> that's why it's *passive*!

# 3D Scanning Taxonomy: Optical - Passive: Stereo

- It is based on the same principle of human stereo vision:
  - two cameras that captures the real-world from two slightly different positions
- Our brains does it automatically though

# 3D Scanning Taxonomy: Optical - Passive: Stereo



# 3D Scanning Taxonomy: Optical - Passive: Stereo



Left Camera



Right Camera

# 3D Scanning Taxonomy: Optical - Passive: Stereo

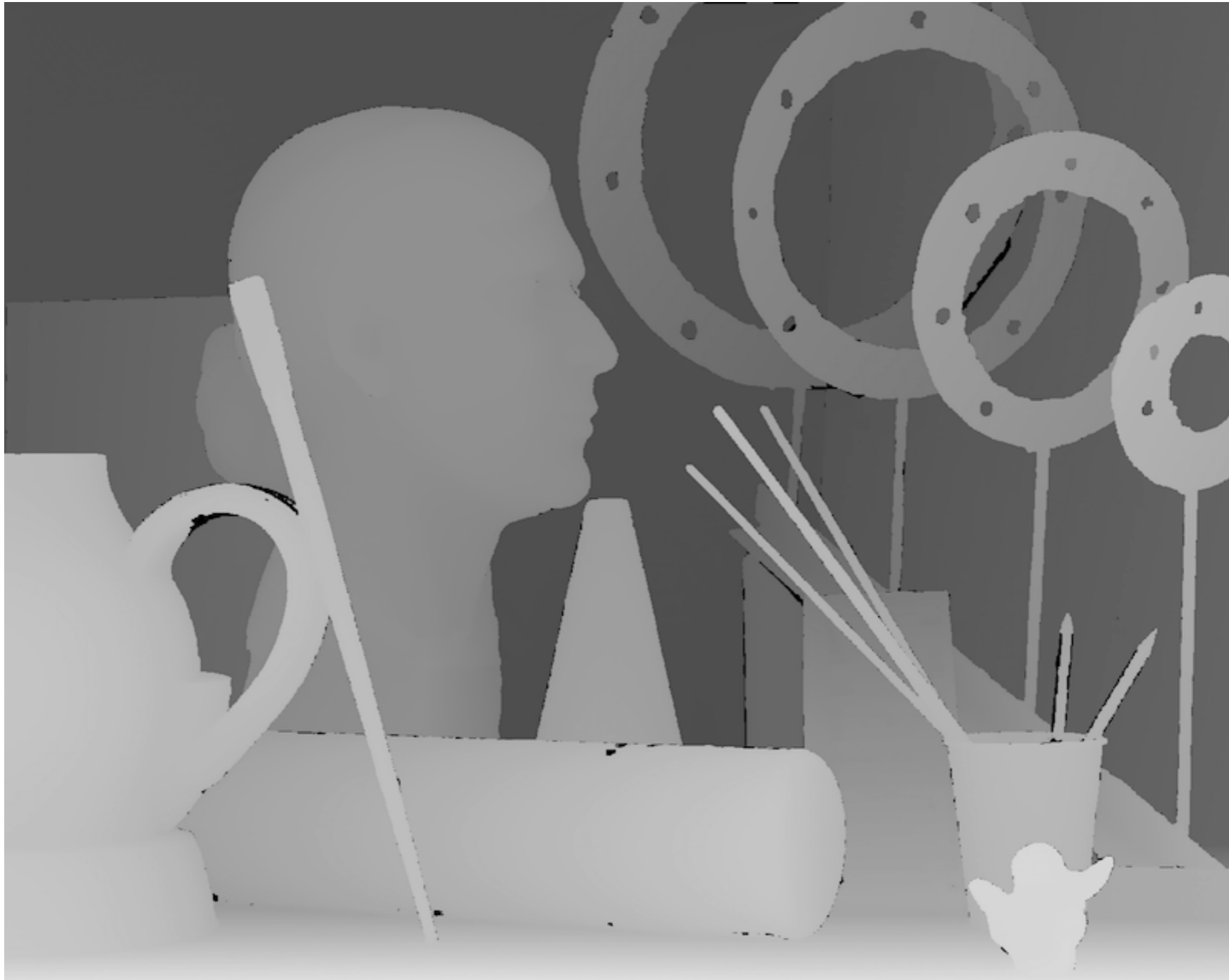


Left Camera

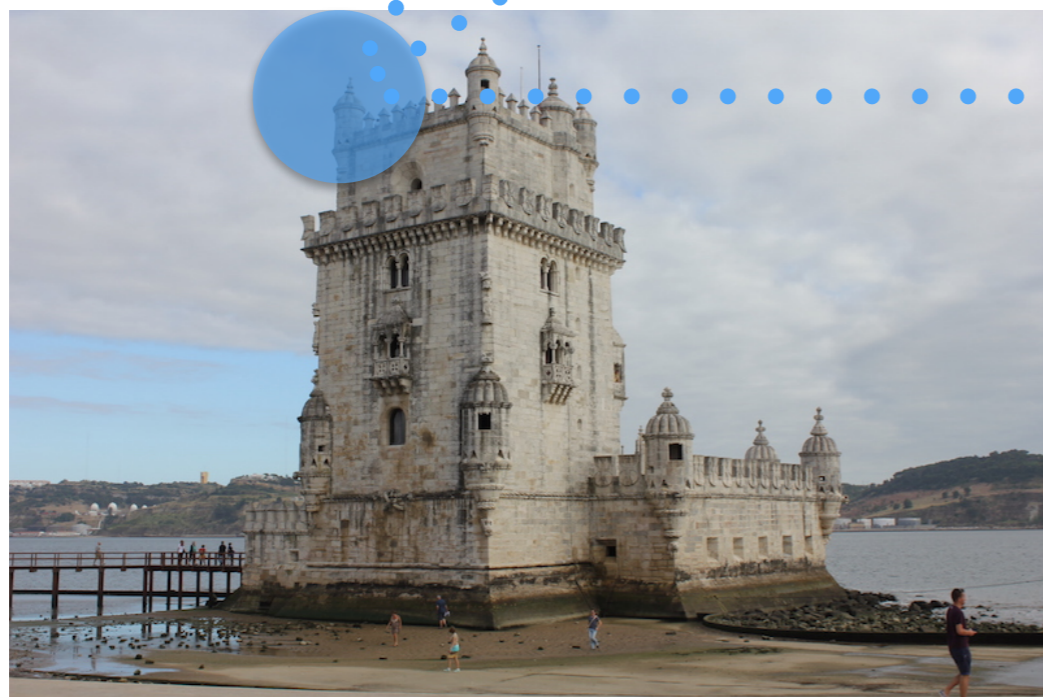
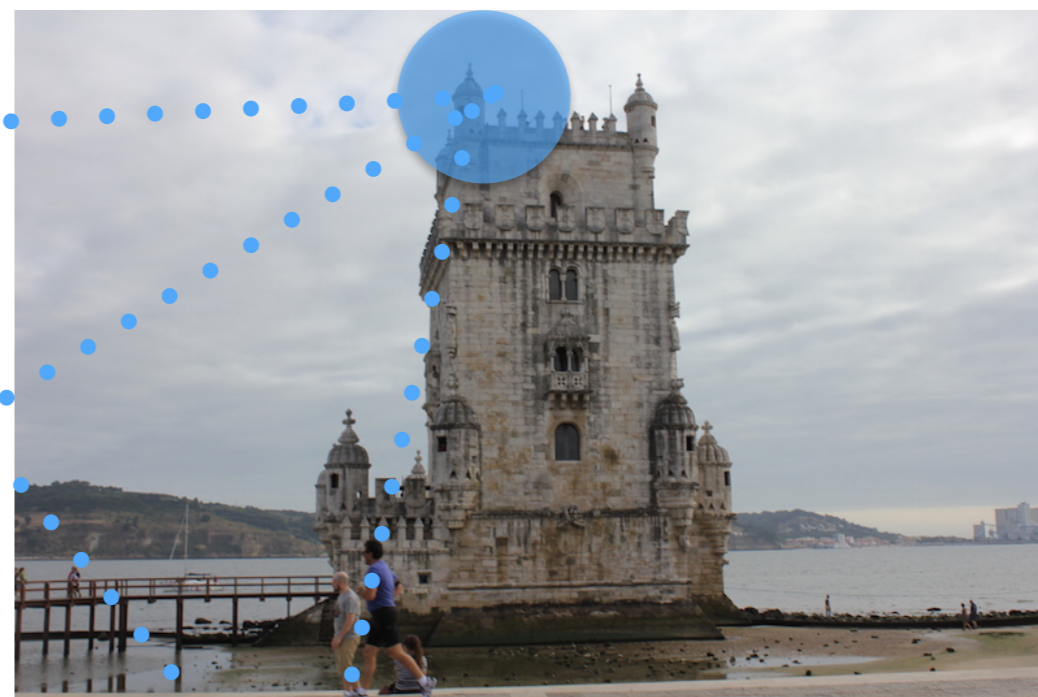


Right Camera

# 3D Scanning Taxonomy: Optical - Passive: Stereo



# 3D Scanning Taxonomy: Optical - Passive: Stereo

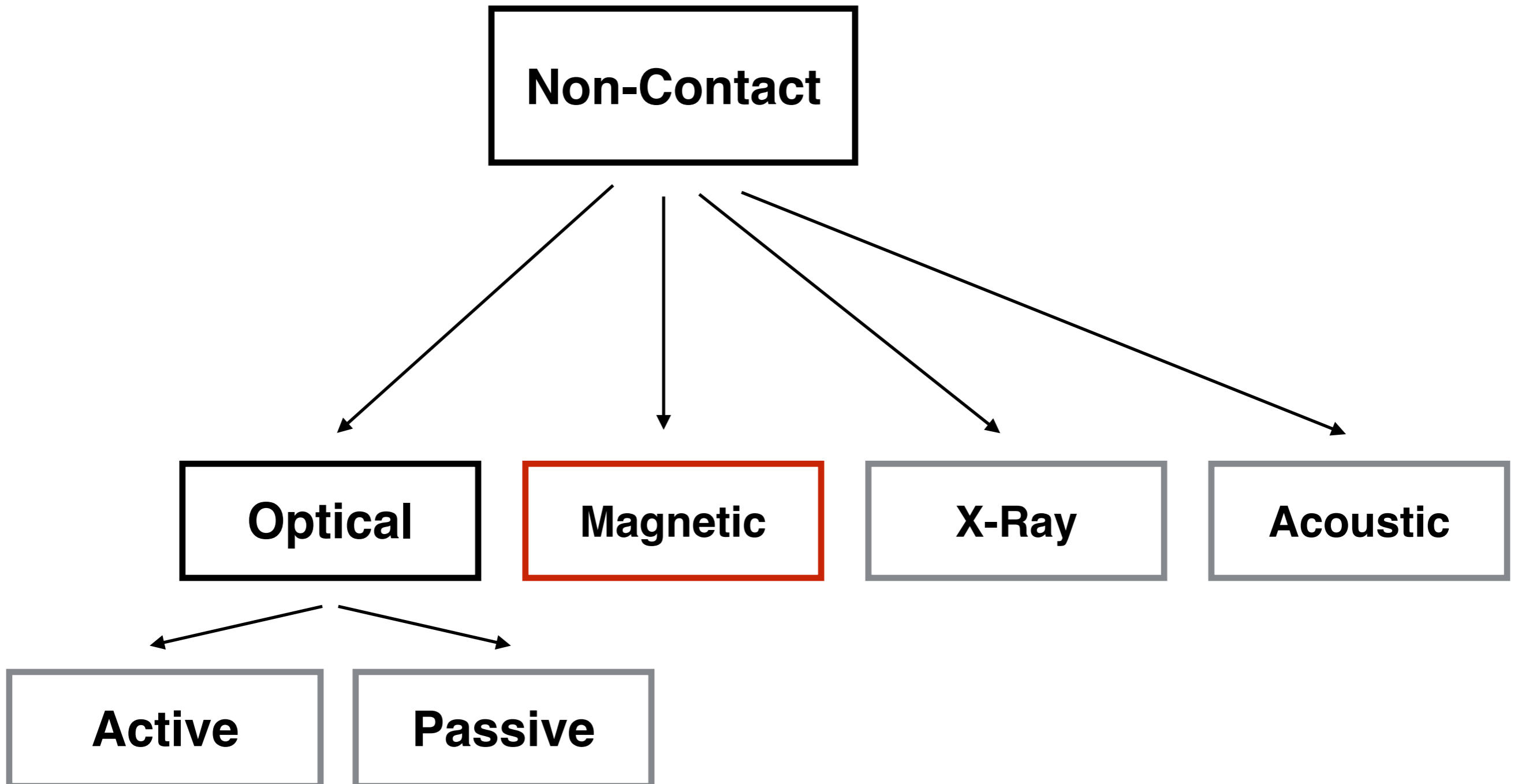




# 3D Scanning Taxonomy: Optical - Passive

- It can be accurate and precise
- Many images are required
- Ideal for: objects with diffuse optical properties
- Uses: reverse engineering, cultural heritage, body capturing, metrology (if calibrated)
- Output data: sparse 3D points or range maps

# 3D Scanning Taxonomy



# 3D Scanning Taxonomy: Magnetic - Magnetic Resonance Imaging (MRI)



Hydrogen atoms in our body are made to emit a radio signal (using a magnetic field) that is detected by the scanner.

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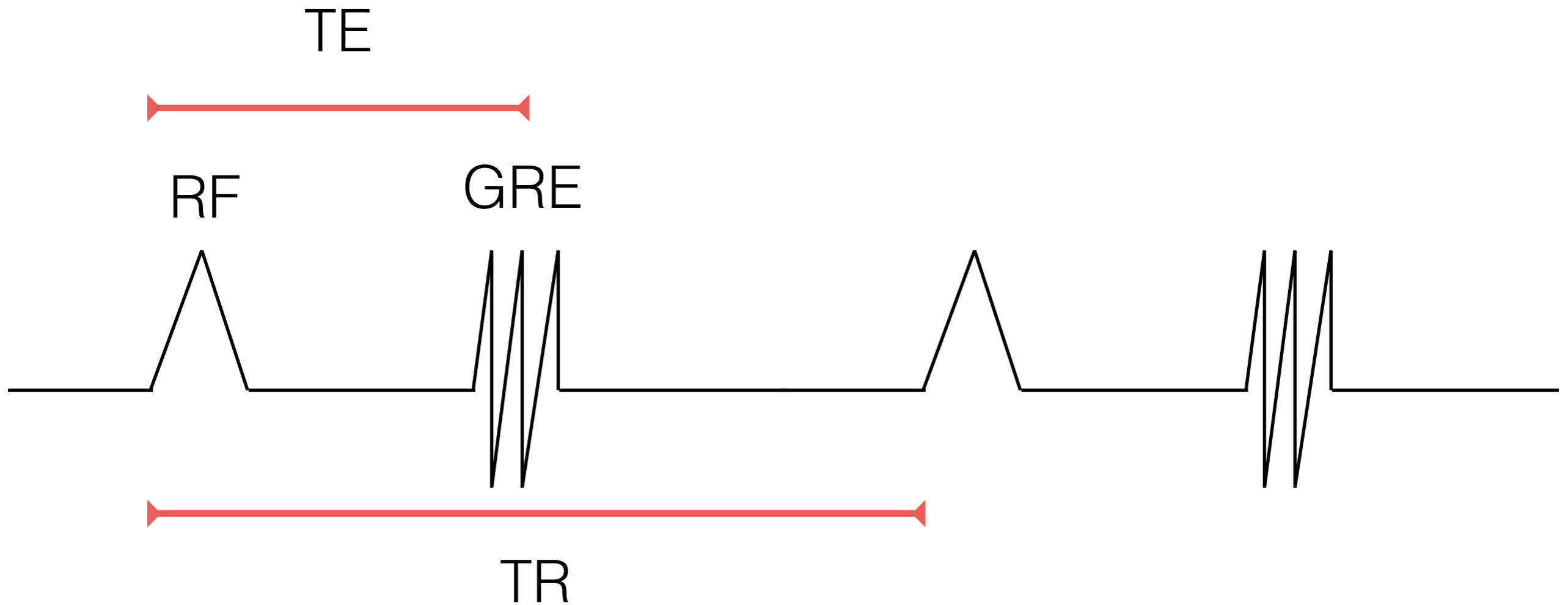
Jan Ainali 2008  
from wikipedia

Philips MRI Scanner

# 3D Scanning Taxonomy: Magnetic - MRI

- T1 weighted images are generated by using short (15ms and 500ms) **time to echo** (TE) and **time of repetition** (TR)
- T2 weighted images are generated by using long (>80ms and >2000ms) TE and TR (also less noise than T1)
- TE is the time between the initial pulse and the echo
- TR is the time between two excitation pulses

# 3D Scanning Taxonomy: Magnetic - MRI

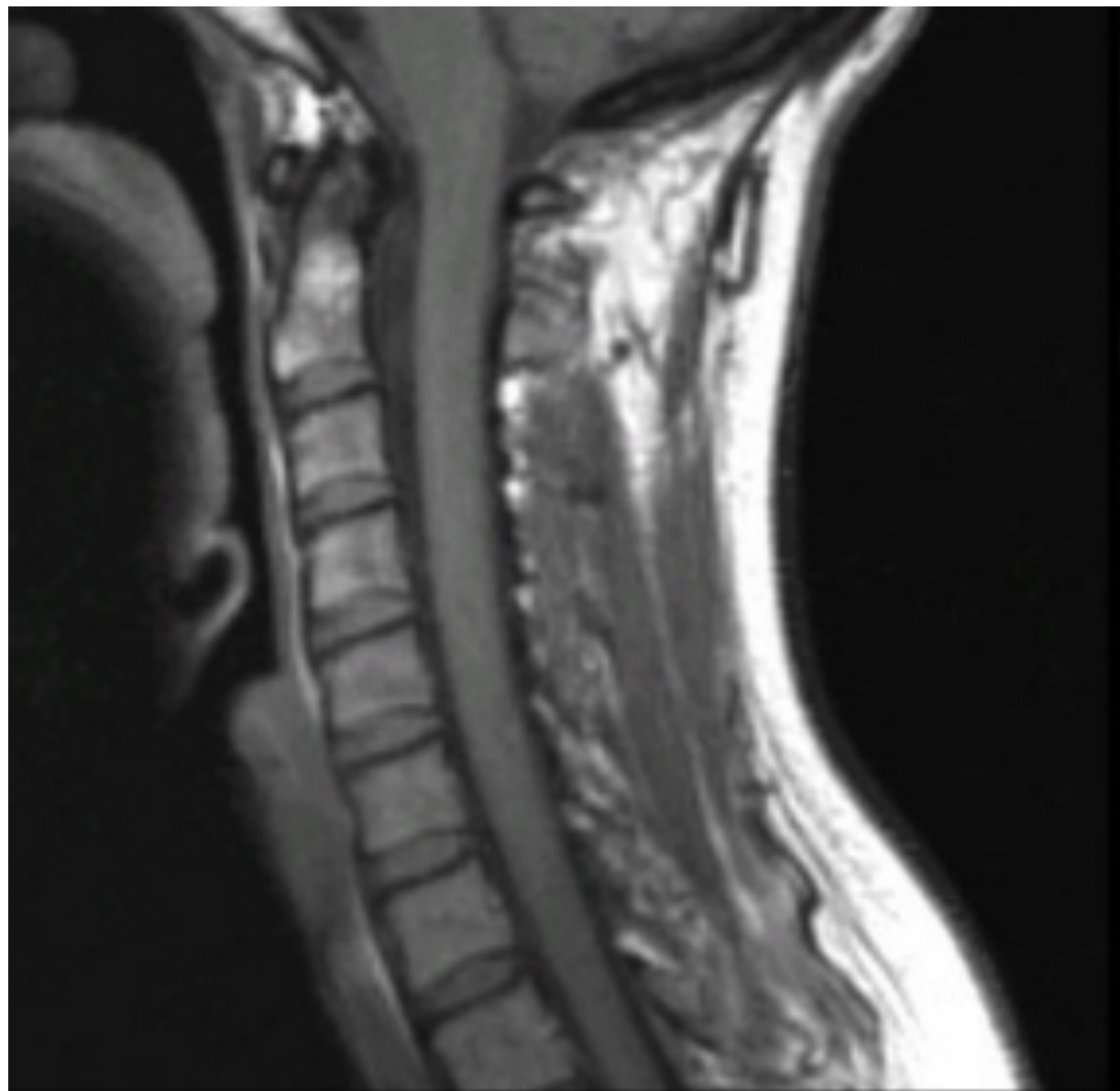


GRE: Gradient of Echo  
RF: Radiofrequency

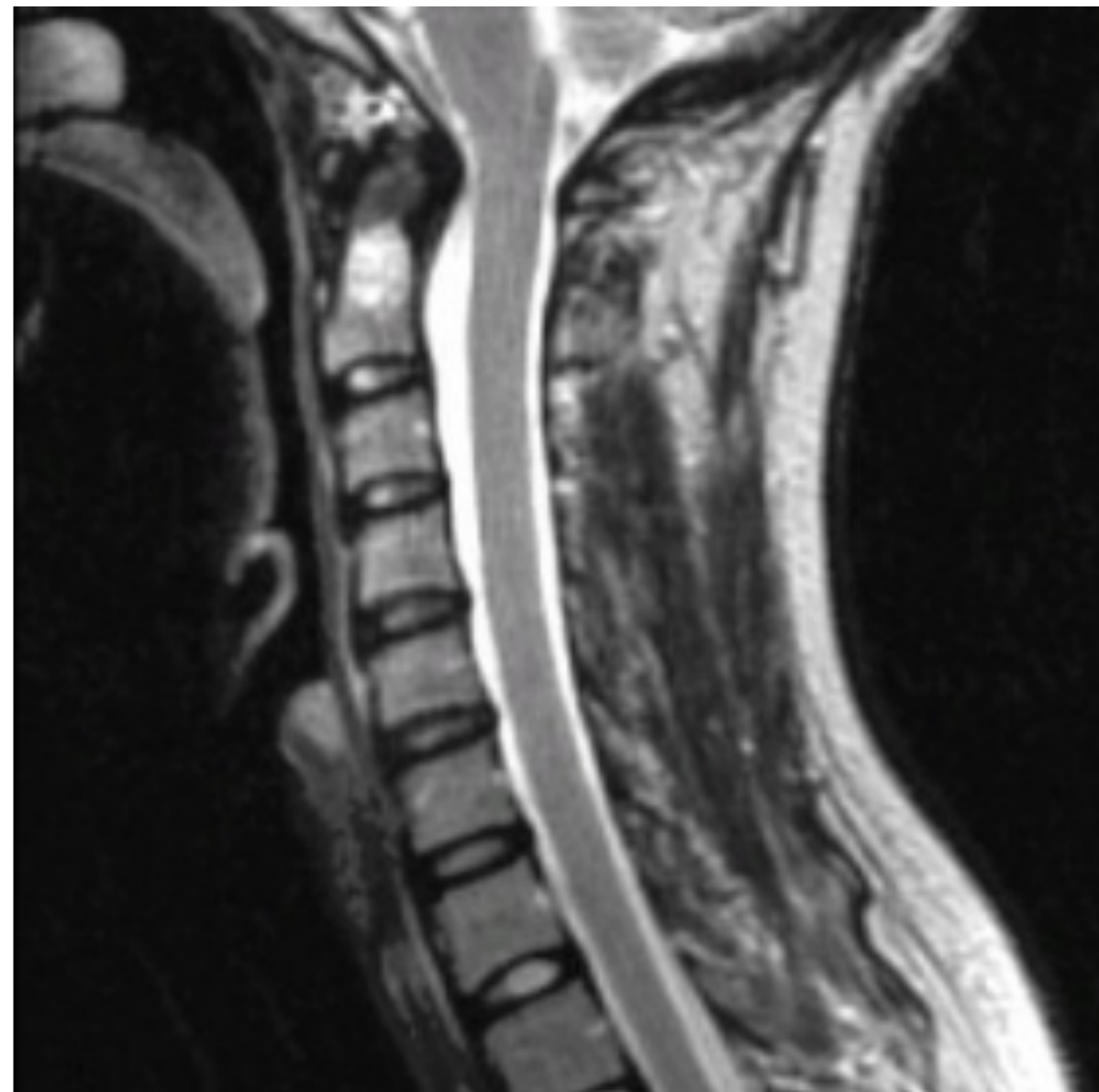
# 3D Scanning Taxonomy: Magnetic - MRI

- T1: tissues with high fat content (e.g., white matter) appear bright and compartments filled with water appears dark:
  - ideal for showing anatomy features
- T2: compartments filled with water (e.g. cerebrospinal fluids) appear bright and tissues with high fat content (e.g. white matter) appear dark:
  - ideal for highlighting pathologies (more water!)

# 3D Scanning Taxonomy: Magnetic - MRI



T1 Weighted



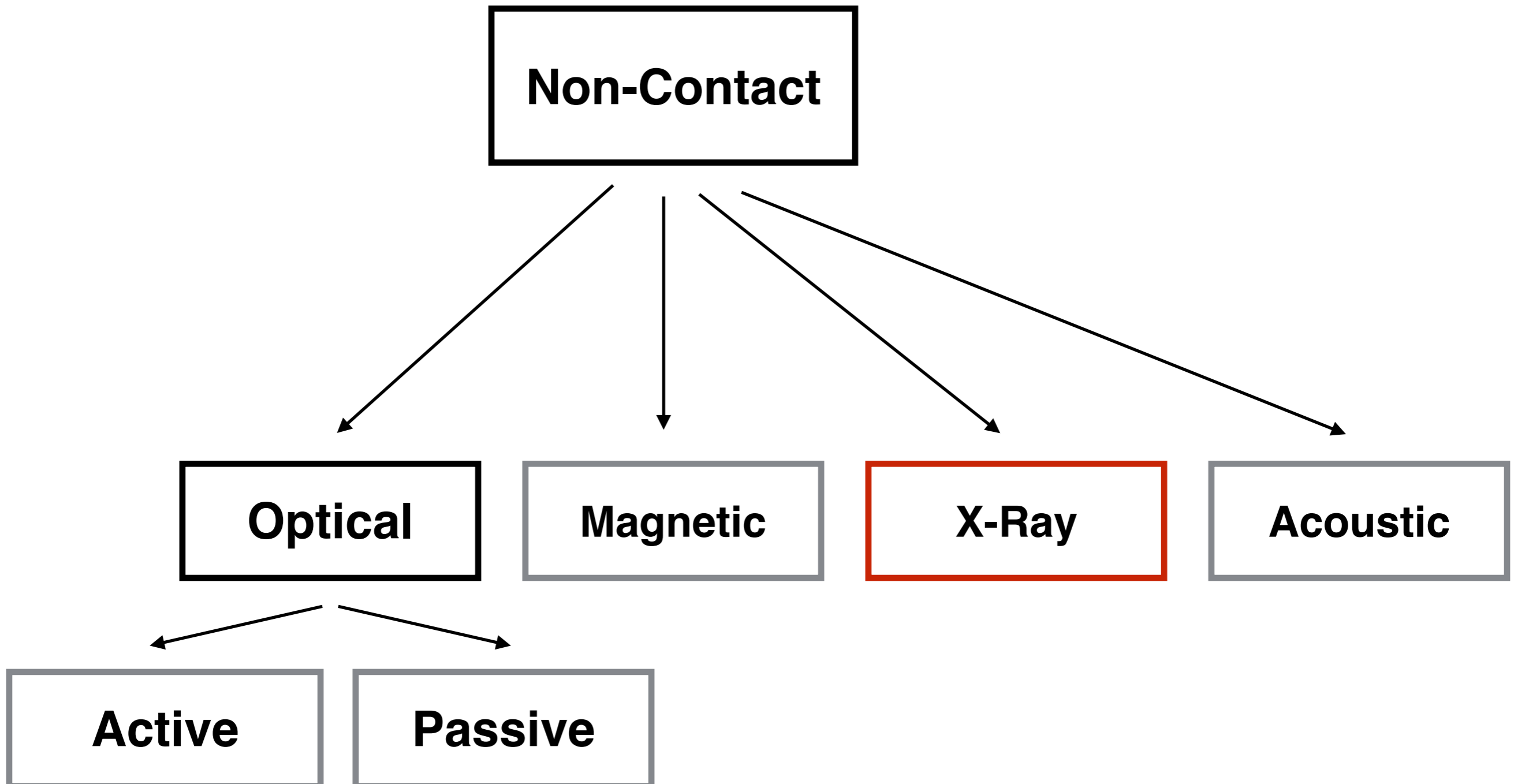
T2 Weighted

# 3D Scanning Taxonomy: Magnetic - MRI

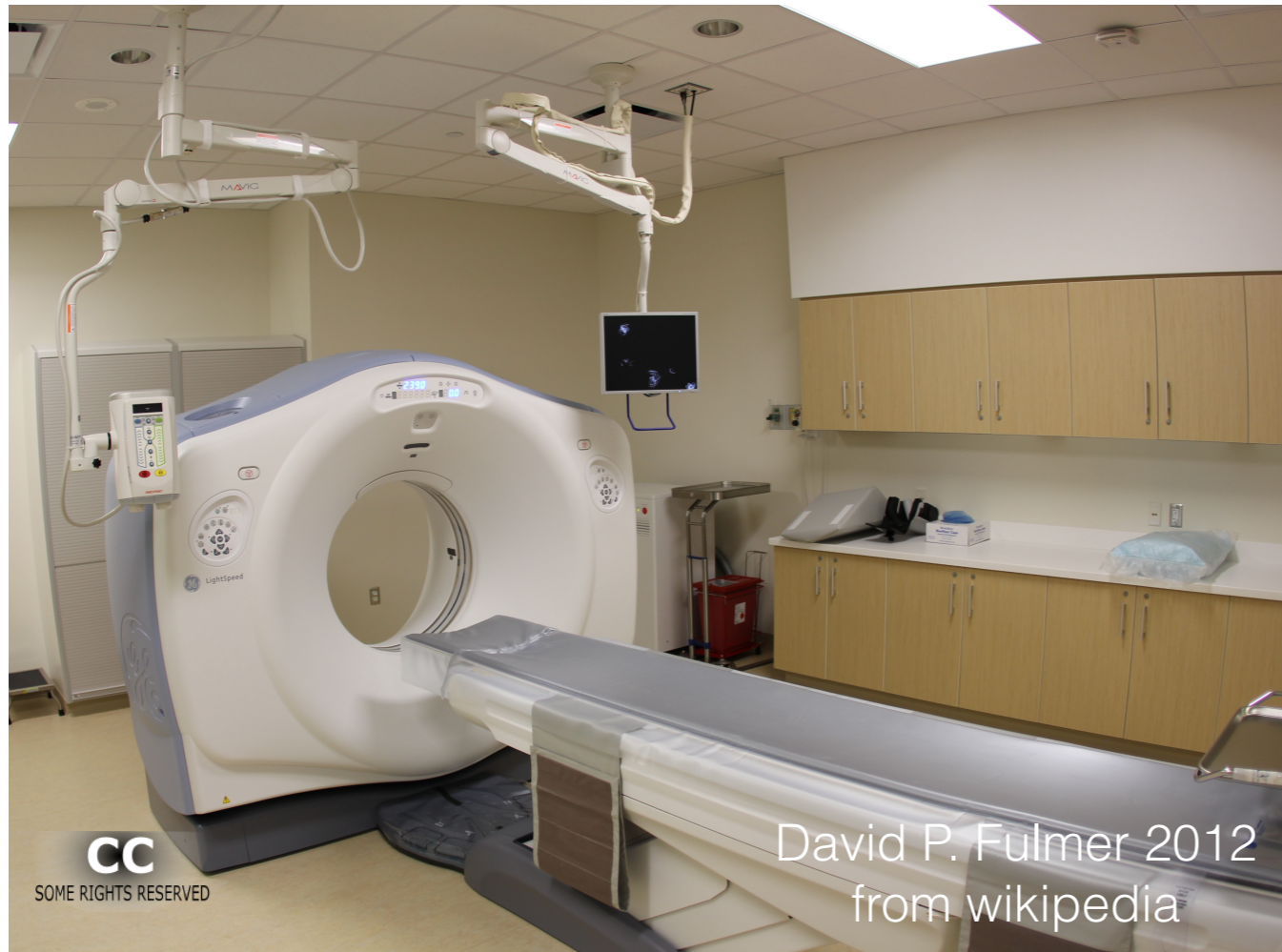
- No hazard, but it requires no metal implant in the patient's body
- It takes long time for a scan; e.g., 15-30 mins
- Costs: they start at \$1 million
- Ideal for: soft tissues, ligaments, tendons, etc.
- Uses: medical imaging, and cultural heritage
- Output data: a 3D volume



# 3D Scanning Taxonomy



# 3D Scanning Taxonomy: X-Ray - Computer Tomography (CT)



CT works by taking X-ray images from different angles to produce cross-sectional images

GE LightSpeed CT scanner

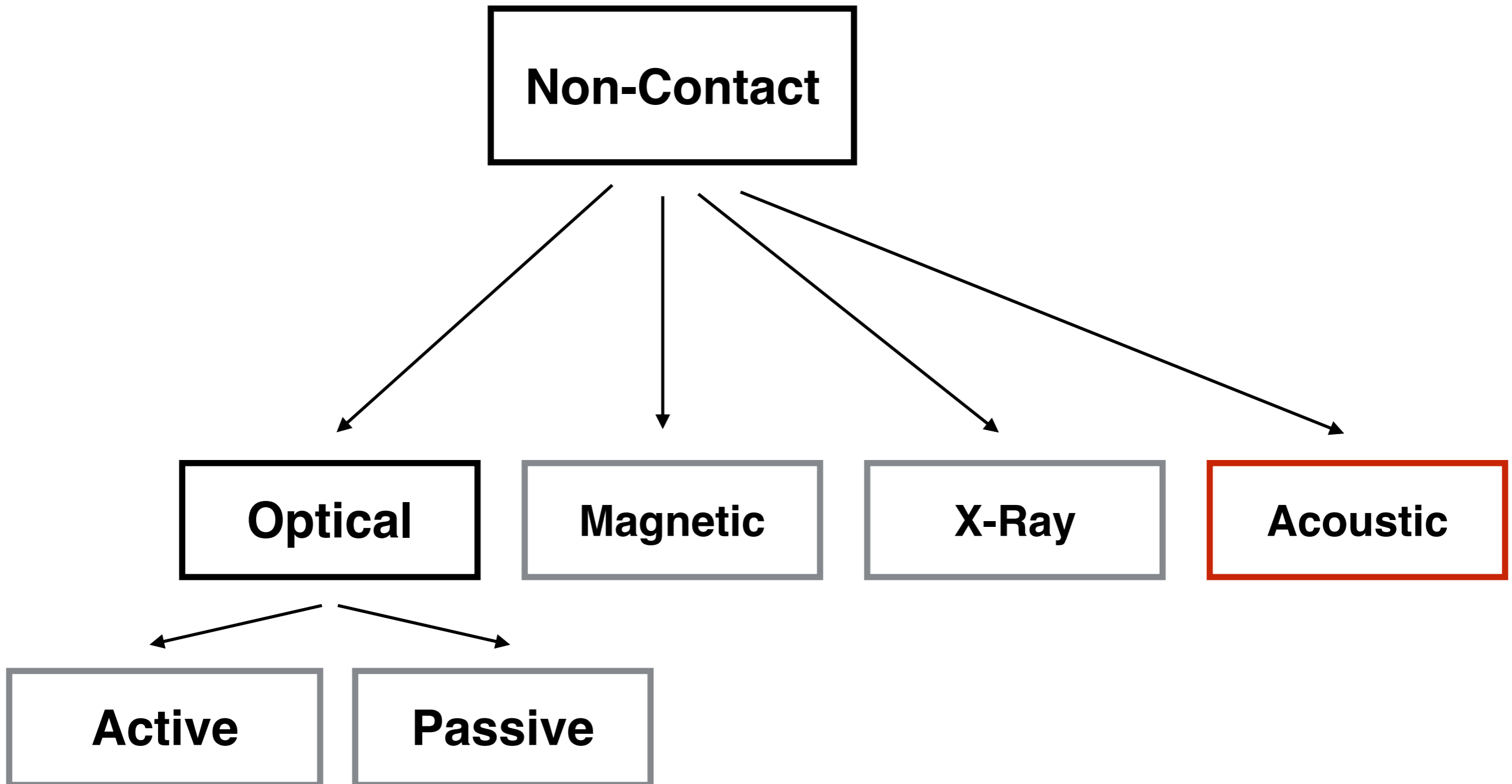
# 3D Scanning Taxonomy: X-Ray - CT

- Hazard for the patient
- It takes long time; e.g., 30 secs - 5 mins
- Costs: they start at \$85,000 - \$500,000
- Ideal for: bones (Ca absorbs X-rays), lungs (contain gas; lower absorption than tissues), chest, and ER (for time)
- Uses: medical imaging, and cultural heritage
- Output data: a 3D volume

# 3D Scanning Taxonomy: X-Ray - CT



# 3D Scanning Taxonomy



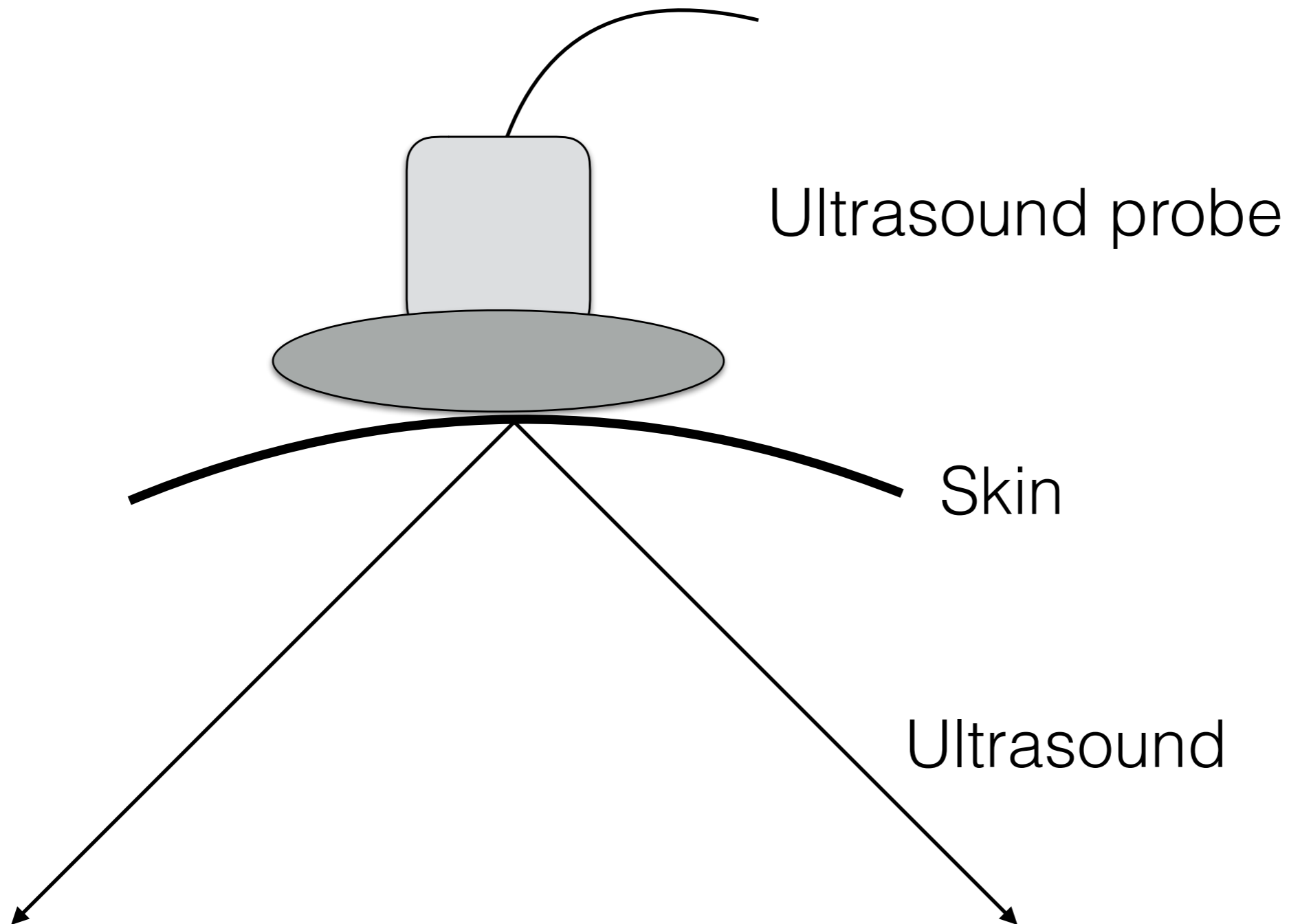
# 3D Scanning Taxonomy: Acoustic: Medical Ultrasound



A probe sends pulses of ultrasounds ( $>20,000\text{Hz}$ )

The sound echoes off the tissue; with different tissues reflecting varying degrees of sound

# 3D Scanning Taxonomy: Acoustic: Medical Ultrasound



# 3D Scanning Taxonomy: Acoustic

- It is real-time!
- Quality-wise it can have speckle; i.e., granular noise
- Ideal for: medical imaging of soft tissues (tendons, muscles, joints, internal organs, etc.); especially during pregnancy. It can not penetrate bones
- Output data: a 3D volume (limited to a pyramid)



# Acknowledgements

- Some images and text are based on work by:
  - Dr. Matteo Dellepiane:
    - <http://vcg.isti.cnr.it/~dellepiane/>
  - Dr. Marco Callieri:
    - [vcg.isti.cnr.it/~callieri/](http://vcg.isti.cnr.it/~callieri/)
- Wikipedia

# Acknowledgements

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  - Dr. Marco Callieri:
    - [vcg.isti.cnr.it/~callieri/](http://vcg.isti.cnr.it/~callieri/)
- Wikipedia

Extra

# 3D Scanning Taxonomy: Magnetic - MRI

- Time of Repetition (TR) is the time between successive radio frequency (RF) pulses:
- A long TR  $\rightarrow$  protons in all tissues relax back into alignment with the main magnetic field
- A short TR  $\rightarrow$  protons from some tissues will be not fully relaxed back before the next measurement

# 3D Scanning Taxonomy: Magnetic - MRI

- Time of Echo (TE) is the time at which the electrical signal induced by the spinning protons is measured:
  - A long TE  $\rightarrow$  to reduce the signal for some tissues such as gray matter (protons go out of phase)
  - A short TE  $\rightarrow$  to reduce dephasing